CHEMICAL AND BIOLOGICAL ENGINEERING

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Chair
Sohail Murad

Faculty with Research Interests
For more information regarding faculty visit the Department of Chemical and Biological Engineering website.

The mission of the Department of Chemical and Biological Engineering is to meet the present and future needs of society and industry by providing state-of-the-art education and research programs. In order to accomplish this mission, the department provides graduate students with:

- Fundamental knowledge and design capability in chemical and biological engineering
- Advanced research programs in core competency areas
- Knowledge of industrial ecology/design for the environment
- Understanding of ethical, economic, and social issues that influence intellectual technological choices
- Leadership and communication skills
- Lifelong learning capabilities

Research Centers and Institutes

Center for Electrochemical Science and Engineering

Center of Excellence in Polymer Science and Engineering
Fouad Teymour, Director

Engineering Center for Diabetes Research and Education
Ali Cinar, Director

Center for Molecular Study of Condensed Soft Matter
Jay Schieber, Director

Center for Complex Systems and Dynamics
Fouad Teymour, Director

Wanger Institute for Sustainable Energy Research
Hamid Arastoopour, Director

Research Facilities

Research facilities of the department include:

Biochemical Engineering Lab
Biointerfaces Lab
Biomaterials Lab
Center for Electrochemical Science and Engineering Lab
Center of Excellence in Polymer Science and Engineering Lab
Computational Fluid Dynamics Lab
Fuel Cell Battery Lab
Fuel Cell Lab
Fluidization Lab
Gas Processing Lab
Hydrogen Storage Lab
Interfacial Phenomena Lab
Light Scattering Lab
Multiphase Flow and Fluidization Lab
Particle Technology Lab

Polymer Characterization Lab
Polymer Reaction Engineering Lab
Porous Media and Core Analysis Lab
Process Control & Optimization Lab
Process Modeling, Monitoring, and Control Lab
Rheology Lab
Riser Lab

The computational facilities of the department include the Advanced Computer Laboratory, and the computer facilities of each research group. All computers are connected to the university computer network by ethernet. Both the PCs and workstations access the multimedia system to provide data visualization and high-quality presentations. Each research lab also has specialized computer facilities. The computational capability for the department is provided by three servers that include both Linux and Windows. Students also have access to the university's computing and network services.

Research Areas

Faculty members conduct numerous projects in the department's core areas of research competency:

Energy and Sustainability

Fuel cells and batteries
Fluidization and gasification
Hybrid systems

Biological Engineering

Molecular modeling
Diabetes
Biomedical and pharmaceutical engineering
Biochemical engineering
Food processing

Advanced Materials

Interfacial and transport phenomena
Nanotechnology
Polymers
Biomaterials

Systems Engineering

Complex systems
Advanced process control
Process monitoring

Admission Requirements

Minimum Cumulative Undergraduate GPA

3.0/4.0

Minimum GRE Scores

- Master's: 295 (quantitative + verbal), 2.5 (analytical writing)
- Master of Science: 304 (quantitative + verbal), 3.0 (analytical writing)
- Ph.D.: 304 (quantitative + verbal), 3.0 (analytical writing)

Minimum TOEFL Scores

80/550 (internet-based/paper-based test scores)

Note: The GRE requirement is waived for professional master's degree applicants who hold a bachelor of science in a related field from an ABET-accredited university in the United States with a minimum cumulative GPA of 3.0/4.0.

Certificate program applicants must possess a bachelor's degree with a minimum cumulative GPA of 2.5/4.0. The GRE is not required.

Meeting the minimum GPA and test score requirements does not guarantee admission. Test scores and GPA are just two of several important factors considered. Admission to graduate study in chemical engineering or biological engineering normally requires the completion of a program leading to a bachelor's degree in chemical engineering or another engineering discipline from an accredited

institution. Depending on the student's background, deficiency courses, some of which may not count toward the degree, may be required. Please see the department's list of applicable undergraduate courses.

Admission to the graduate degree program in biological engineering requires one college-level semester of biology. Students not meeting this requirement may be admitted, but will have to take CHE 412 to remove the deficiency.

Degree Programs

- Master of Biological Engineering
- Master of Chemical Engineering
- Master of Computational Engineering, Computational Chemical Engineering Track
- Master of Pharmaceutical Engineering
- Master of Science in Chemical Engineering
- Doctor of Philosophy in Chemical Engineering

Certificate Programs

The department offers six graduate certificate programs. These programs provide students with post-baccalaureate knowledge of an area of specialization within chemical engineering. Students in these programs register as certificate students.

Certificate programs typically require a set of three to four courses that must be completed in three years with a minimum GPA of 3.0/4.0 (Note: some courses may have prerequisites). Students who are admitted to master's degree programs may apply coursework previously taken in a certificate program toward the requirements for the master's degree.

- Biological Engineering
- Current Energy Issues
- Pharmaceutical Engineering
- Polymer Science and Engineering
- Process Operations Management

Course Descriptions

CHE 501
Transport Phenomena
The equations of change (mass, momentum, and energy transport) for single phase and single component, multiphase and multicomponent systems. Analytical and numerical solution to equations of change for Velocity, Temperature and Concentration distribution with more than one independent variable in chemical and biological processes. Dimensional analysis for problem reduction.
Prerequisite(s): (CHE 301 with min. grade of C and CHE 302 with min. grade of C) or CHE 406 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 503
Thermodynamics
Laws of thermodynamics applied to chemical and biological engineering problems, properties of real fluids, phase and chemical equilibria, applications to chemical and biological processes and auxiliary equipments. Core course.
Prerequisite(s): CHE 451 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 506
Entrepreneurship and Intellectual Property Management
Graduate standing or consent of instructor. This course aims to introduce and develop a number of diversified professional skills necessary for success in an engineering research and development environment. Selected topics covered in the areas of technology entrepreneurship, opportunity assessment, creativity and innovation, project management, management of organizational change, entrepreneurial leadership, and intellectual property management.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 508
Process Design Optimization
Organization of the design problem and application of single and multi-variable search techniques using both analytical and numerical methods.Prerequisite:An undergraduate course in process design.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 514
Process Analytical Technology
Process Analytical Technology (PAT) is introduced as a framework to enhance process understanding and assist in the development of reliable and efficient pharmaceutical operations. The course covers the definition of critical performance attributes within the context of FDA regulations; an overview of analytic measurement methods of chemical, physical and biological quantities; statistical data analysis and chemometric methods, including statistical process monitoring, multivariate analysis and parameter estimation; and design of real-time decision systems, including automatic control operations and risk-based analysis of final product quality. Prerequisite: BS in engineering or equivalent.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 516
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

CHE 525
Chemical Reaction Engineering
Advanced treatment of chemical kinetics and reactor systems including non-isothermal, nonideal flow systems. Modeling of complex reactions, catalysis and heterogeneous reactor analysis. Reactor stability concepts. Core course.
Prerequisite(s): CHE 423 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 530
Advanced Process Control
State space, transfer function and discrete-time representations of process systems. Control system design. Interaction assessment. Multivariable and model predictive-control techniques. Core course.
Prerequisite(s): CHE 435 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 535
Applications of Mathematics to Chemical Engineering
Mathematical techniques and their application to the analytical and numerical solution of chemical engineering problems. The analytical component includes review of matrices and determinants, as well as solution of ordinary, partial differential and integral equations. The numerical component includes iterative solution of algebraic equations, numerical analysis and solution of ordinary differential equations. Core course.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 536
Computational Techniques in Engineering
Advanced mathematical techniques, numerical analysis, and solution to problems in transport phenomena, thermodynamics, and reaction engineering. Review of iterative solution of algebraic equations. Nonlinear initial and boundary value problems for ordinary differential equations. Formulation and numerical solution of parabolic, elliptic, and hyperbolic partial differential equations. Characteristics, formulation, and numerical solution of integral equations. Solution of transient two-phase flow problems using CFD codes.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 538
Polymerization Reaction Engineering
The engineering of reactors for the manufacture of synthetic polymeric materials, commercial processes for manufacture of polymers of many types, polymer chemistry and engineering reactor design.
Prerequisite(s): CHE 423 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 541
Renewable Energy Technologies
The course will cover three topics related to renewable Energy Technologies. 1. Review of renewable energy sources; solar, wind, biomass, etc. 2. Energy storage and conversion with emphasis on batteries and fuel cells 3. Hydrogen as an energy carrier and the Hydrogen Economy.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 542
Fluidization and Gas-Solids Flow Systems
Fluidization phenomena (bubbling, slugging, elutriation, and jets in fluidized beds). Multiphase flow approach to fluidization and gas/solids flow systems. Kinetic theory approach to fluid/particle flow systems. Analysis of flow of particles in pneumatic conveying lines (dilute flow) and stand pipe (dense flow). Hydrodynamic analysis of spouted and circulating fluidized beds. Examples from current literature on applications of multiphase flow.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 543
Energy, Environment, and Economics
The linkage of energy, environmental and economic issues. The impact of energy supply and end use on human well-being and the ecosystem. A comprehensive approach to the resolution of resource, technical, economic, strategic, environmental, socio- and geopolitical problems of the energy industries. Pathways to a sustainable global energy system.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 545
Metabolic Engineering
Cellular metabolism, energetics and thermodynamics of cellular metabolism, regulation of metabolic pathways, metabolic flux analysis, metabolic control analysis, analysis of metabolic networks, synthesis and manipulations of metabolic pathways, applications - case studies.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 551
Advanced Transport Phenomena
Formulation, solution and interpretation of problems in momentum, energy and mass transport phenomena that occur in chemical and biological processes.
Prerequisite(s): CHE 406 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 553
Advanced Thermodynamics
Advanced thermodynamics for research-oriented graduate students. The course covers the fundamental postulates of thermodynamics and introductory statistical mechanics, with applications to pure fluids, fluid mixtures, elastic solids, surfaces and macromolecules.
Prerequisite(s): CHE 451 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 555
Polymer Processing
Analysis of momentum, heat and mass transfer in polymer processing operations. Polymer processes considered include extrusion, calendaring, fiber spinning, injection molding, and mixing.
Prerequisite(s): CHE 406 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 560
Statistical Quality and Process Control
Basic theory, methods and techniques of on-line, feedback, quality-control systems for variable and attribute characteristics. Methods for improving the parameters of the production, diagnosis and adjustment processes so that quality loss is minimized. Same as MMAE 560.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 565
Fundamentals of Electrochemistry
Thermodynamics and potential, Marcus theory, charge transfer kinetics and mass transport of simple systems. Electrode reactions couple with homogeneous chemical reactions. Double layer structure and adsorbed intermediates in electrode processes. Potential step and potential sweep methods.
Prerequisite(s): (CHE 433 and CHE 451) or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 566
Electrochemical Engineering
Basic concepts of electrochemistry used in electrochemical reactor analysis and design. Thermodynamics, kinetics and transport processes in electrochemical systems, current and potential distribution, corrosion engineering, electrodeposition, batteries and fuel cells, industrial electrolysis, and electrosynthesis.
Prerequisite(s): (CHE 433 and CHE 451) or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 567
Fuel Cell Fundamentals
A detailed study of the thermodynamics, electrochemistry, electrode kinetics and materials aspects of fuel cells with an emphasis on polymer electrolyte fuel cells. The course will include a vigorous laboratory component and will cover the development of detailed data analysis procedures. A part of the course will cover current trends and interests through the critical discussion of recent archival publications.
Lecture: 2 **Lab:** 1 **Credits:** 3

CHE 575
Polymer Rheology
Flow of viscoelastic fluids, integral and differential constitutive equations from continuum and molecular considerations, methods of experimental evaluations.
Prerequisite(s): CHE 406 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 577
Bioprocess Engineering
Application of engineering principles to the biological production processes. Enzyme kinetics, cell culture kinetics, transport phenomena in cells, membranes, and biological reactors ,genetics, bioseparation and downstream processing, energetics of metabolic pathways, operation modes of cell cultures, mixed and their applications.
Prerequisite(s): CHE 423 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 580
Biomaterials
Metal, ceramic, and polymeric implant materials. Structure-property relationships for biomaterials. Interactions of biomaterials with tissue. Selection and design of materials for medical implants.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 582
Interfacial and Colloidal Phenomena with Applications
Applications of the basic principles of physical chemistry, surfactants and interfacial phenomena, surface and interfacial tension, adsorption of surfactants from solutions, spreading, contact angles, wetting, electro kinetic phenomena, rheology, dynamic interfacial properties, mass transport across interfaces. Applications include emulsions, foams, dispersions, tribology, detergency, flotation, enhanced oil recovery, suspension, emulsion polymerization and liquid membranes.
Prerequisite(s): (CHE 406 with min. grade of C and CHE 451 with min. grade of C) or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 583
Pharmaceutical Engineering
Application of transport phenomena, and reaction engineering to pharmaceutical processes. Heat and mass transfer in bioreactors and the fluidized beds. Drying, coating and granulation. Environmental and economical issues in the pharmaceutical process. Examples from industrial processes and current literature.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 584
Tissue Engineering
Growth and differentiation of cells and tissue. In vitro control of tissue development. In vivo synthesis of tissues and organs. Transplantation of engineered cells and tissue. Techniques and clinical applications of tissue engineering.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 585
Drug Delivery
Principle of diffusion in liquids membrane and polymers, and methods for measurement and analysis of diffusion coefficient. Principle of molecular transport in polymeric material, and drug solubility in polymers. Intravenous infusion, and polymer drug delivery systems. Process involved and kinetics of solute release. Design and optimization of drug delivery system based on pharmacokinetic/ pharmacodynamic requirements.
Lecture: 3 **Lab:** 0 **Credits:** 3

CHE 591
Research and Thesis for M.S. Degree
Credit: Variable

CHE 593
Seminar in Chemical Engineering
Presentations on recent developments in the field by academic and industrial visitors.
Lecture: 0 **Lab:** 1 **Credits:** 1

CHE 594
Special Projects
Advanced projects involving computer simulation, modeling or laboratory work. (Credit: 1-6 hours.)
Credit: Variable

CHE 597
Special Problems
Independent study and project. (Credit: variable)
Credit: Variable

CHE 600
Continuance of Residence
Lecture: 0 **Lab:** 1 **Credits:** 1

CHE 691
Research and Thesis for Ph.D. Degree
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 tropic 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