CHEMICAL & BIOMOLECULAR ENGINEERING (CBE)

CBE 10115 Exploring Chemical Engineering Topics through Food Design (3 Credit Hours)
This is a project based course for first-year engineering students to learn about chemical engineering topics. After completing this course, students will be able to identify major chemical engineering concepts and create simple process diagrams of an industrial food process. In addition, students will gather and analyze data in order to design a food product with appropriate process diagrams, safety considerations, and economic analysis.

CBE 20255 Introduction to Chemical Engineering Analysis (3 Credit Hours)
This is a foundation course in which the students learn to apply the concepts of material and energy balances to problems involving chemical processes, biological systems and environmental phenomena. Within this context, they learn problem-solving techniques and acquire a working knowledge of phase equilibria, physical properties, and computer applications.
Prerequisites: (MATH 10560 or MATH 10092 or MATH 10460 or MATH 10860) and (CHEM 10171 or CHEM 10172 or CHEM 10182) and (PHYS 10310 or PHYS 10093)
Corequisites: CBE 22255

CBE 20258 Numerical and Statistical Analysis (3 Credit Hours)
Algorithms for solving algebraic (e.g., Gaussian Elimination, PLU decomposition, etc.) and differential equations (e.g., Runge-Kutta, Shooting methods) are derived and implemented using Matlab. Statistics and error analysis constitute a significant part of the course.
Prerequisites: CBE 20255
Corequisites: CBE 22258

CBE 20260 Chemical Engineering Thermodynamics I (3 Credit Hours)
The course provides an introduction to modern applied thermodynamics, with a focus on aspects relevant to chemical engineers. It begins with the first law energy balance, followed by the development of the second law entropy balance. Thermodynamic constitutive equations for gases and liquids are developed from a molecular-level perspective, followed by applications involving thermodynamic cycles and energy conversion.
Prerequisites: CBE 20255
Corequisites: CBE 22260

CBE 20261 Science of Eng. Materials (3 Credit Hours)
This is an introductory course that examines the relationship between the structure, processing, and properties of engineering materials. Common engineering materials, including steel, concrete, ceramics, and polymers are discussed. Mechanical, chemical, electrical, and magnetic properties of various materials are examined. The process dependence of microstructural development and defects levels are described.

CBE 20280 Chemical and Biomolecular Engineering Thermodynamics I (3 Credit Hours)
The course provides an introduction to modern applied thermodynamics, with topics selected for chemical engineers who have an interest in biological and physiological systems. It begins with the first law energy balance, followed by the development of the second law entropy balance. These are used to provide insight and solve problems that arise in e.g., power cycles, physiological processes and chemical production. Thermodynamic constitutive equations for gases and liquids are developed from a molecular-level perspective and applied to the prediction of physical and chemical properties of pure substances.
Corequisites: CBE 22280

CBE 20290 Career Choices for Engineers (1 Credit Hour)
A seminar series featuring selected speakers who are employed or consult with high tech business enterprises of both national and global involvement. The presentations and open symposium format will emphasize business ethics, competitive pressures, people skills, and most importantly, career opportunities for engineering graduates. This course is repeatable and the Notre Dame Alumni speakers will be different each semester.
Course may be repeated.

CBE 22255 Introduction to Chemical Engineering Tutorial (0 Credit Hours)
Tutorial for Introduction to Chemical Engineering.
Corequisites: CBE 20255

CBE 22258 Numerical and Statistical Analysis Tutorial (0 Credit Hours)
Tutorial Sessions for Computer Methods CBE20258
Corequisites: CBE 20258

CBE 22260 Chemical Engineering Thermodynamics I Tutorial (0 Credit Hours)
Tutorial for Chemical Engineering Thermodynamics I
Prerequisites: CBE 20255
Corequisites: CBE 20260

CBE 22261 Sci of Eng Materials-Tutorial (0 Credit Hours)
Tutorial for CBE 20261 Science of Engineering Materials
Corequisites: CBE 20261

CBE 22280 Chemical and Biomolecular Engineering Thermodynamics I Tutorial (0 Credit Hours)
Tutorial for CBE 20280
Corequisites: CBE 20280

CBE 24255 Bioprocess Engineering Principles (3 Credit Hours)
This module will provide students with an overview of the fundamental principles and concepts involved in Bioprocess Engineering. The introductory lectures will focus on the importance of bioprocess engineering in the pharmaceutical, biopharmaceutical, food processing and environmental sectors. The types of microorganisms involved in industrial bioprocesses and an overview of the upstream and downstream bioprocessing will be examined. The module will examine the production of industrially important products like antibiotics, alcohol and foodstuffs. It will introduce the key role of bioprocesses in sustainability and circular bio-economy. The module will provide students with an introduction to quantitative aspects of cell growth and stoichiometry as a foundation for bioreaction engineering.

CBE 26497 Directed Readings (0-3 Credit Hours)
Course requires the student to explore various readings chosen by the professor.

CBE 27099 Special Studies (0-3 Credit Hours)
Small group or individual study in an undergraduate subject not offered by a University course or not offered in the semester needed. The student or group of students is directed by a faculty member.

CBE 28901 Undergraduate Research (1 Credit Hour)
This is the course that freshmen and sophomore students should sign up for as their first experience in research. This is a one credit course, and involves a minimum commitment of 4-5 hours/wk. This course is S/U, may be taken more than once, but does not satisfy the Engineering/technical elective degree requirement.
Course may be repeated.

CBE 28980 ChemE Car (1 Credit Hour)
As part of the AICHE Chem-E-Car Competition, students design and build a small car, the size of a shoebox, that is powered by a chemical reaction.
Course may be repeated.

CBE 30235 Introduction to Nuclear Engineering (3 Credit Hours)
Electrical energy generation is a huge and growing market as the world attempts to reduce reliance on fossil fuels. Apart from direct conversion of energy sources (e.g., photovolatics and wind/water energy), the generation of electricity revolves around the production of heat (by any source) and then conversion of that to electricity through a steam turbine. Nuclear energy is a carbon-free way of producing this heat. In this course we shall examine the key facets of this way of generating heat: how a sustained fission chain reaction can be safely achieved, how the heat generated can be safely removed, and how the radioactive waste products can be safely disposed of. The course will introduce the students to the fundamentals of fission, including concepts such as neutron capture cross section, reactor poisoning, cladding and shielding, as well as reactor design. Much of the focus will be on conventional pressurized water reactors (PWRs), however the many alternative coolant approaches such as liquid metal and high temperature gas reactors will also be discussed. The course will finish with a discussion of the new small modular reactors (SMR) under development, as well as a discussion of the current status of waste disposal.

CBE 30315 Applying Chemical Engineering Topics in Food Design and Processing (3 Credit Hours)
This is a problem-based learning course for upper-level students in chemical engineering. Students will identify and apply chemical engineering concepts and processes learned in previous chemical engineering coursework as they pertain to food processing. Examples will range from home kitchen cooking to large-scale food processing systems. Students will learn about the basic composition of foods, methods of preservation, common reactions, and food morphology. The course will be structured with a traditional lecture as well as laboratory style classes that involve working directly with food materials. Students will gather and analyze data about a food product and produce process diagrams, consider safety implications, and create basic economic analysis along with creating a prototype of a student-defined food product.

CBE 30338 Data Analytics, Optimization, and Control (3 Credit Hours)
Dynamic modeling, data analytics, optimization, and control are essential to modern chemical technologies that enable precision medicine, sustainable energy, semiconductors, access to clean water, and beyond. In CBE 30338, students combine their knowledge of chemical engineering fundamentals (e.g., thermodynamics, transport, kinetics) and data analytics to develop dynamic models of diverse chemical technologies and processes. These models enable the design and optimization of control systems that use feedback to reject disturbances and drive systems to steady-state setpoints. CBE 30338 combines state-space modeling with modern computational and statistical methods to cover industrially relevant topics such as model predictive control, parameter estimation, and optimization. Students master techniques in hands-on experiments and a final semester project.
Prerequisites: CBE 20258
Corequisites: CBE 32338

CBE 30355 Transport Phenomena I (3 Credit Hours)
Basic conservation principles of energy, mass, and momentum are used to derive the integral and differential forms of the transport equations. These equations are used to solve fluid flow problems of both fundamental and practical interest.
Prerequisites: (MATH 30650 (may be taken concurrently) or MATH 326) and CBE 20255

CBE 30356 Transport Phenomena II (3 Credit Hours)
Integral and differential transport equations are applied to the solution of heat and mass transfer problems of interest to chemical engineers.
Prerequisites: CBE 30355 or CBE 30357 or CBE 34355 or AME 34331
Corequisites: CBE 32356

CBE 30357 Biotransport (3 Credit Hours)
This course is an introduction to momentum transport with applications to biological and medical systems. It will serve as a replacement for CBE 30355 for interested students.

CBE 30361 Science of Engineering Materials (3 Credit Hours)
This is an introductory course that examines the relationship between the structure, processing, and properties of engineering materials. Common engineering materials, including steel, concrete, ceramics, and polymers are discussed. Mechanical, chemical, electrical, and magnetic properties of various materials are examined. The process dependence of microstructural development and defects levels are described.
Prerequisites: CHEM 10114 or CHEM 10116 or CHEM 10118 or CHEM 10121
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 30367 Chemical Engineering Thermodynamics II (3 Credit Hours)
Principles of phase and chemical equilibria are defined and used in the solution of chemical engineering problems drawn from the traditional process industries, biological systems, materials processing, pharmaceutical manufacturing and other industries.
Prerequisites: CBE 20260
Corequisites: CBE 32367

CBE 30370 Phase Equilibria and Separations (3 Credit Hours)
The principles of phase and chemical equilibria are defined and used in the solution of chemical engineering problems. Example problems are drawn from the grand challenges that require input from chemical engineers to be addressed: developing sustainable chemical manufacturing and energy generation processes, engineering better medicines, lowering pharmaceutical manufacturing costs, and designing sustainable materials. This course demonstrates the application of the principles of phase equilibria to the design and characterization of stagewise separation processes. Both graphical and rigorous numerical techniques are used, and the general procedures applicable to many specific processes are emphasized. Example separation problems are drawn from the need to manage emissions into the environment, to meet society's demand for clean drinking water, and to produce low cost therapeutics, among several other relevant challenges.
Prerequisites: CBE 20260 or CBE 20280
Corequisites: CBE 32370

CBE 30386 Introduction to Bioengineering (3 Credit Hours)
This course provides basic science knowledge and engineering practices used by biomedical engineers toward solving problems in human medicine. Topics will include an overview of bioengineering and modern biology, introduction of cell/molecular/genetic engineering principles and the use of engineering analysis to describe living systems, starting with mass and energy balances to understand cell growth and signal transduction. Examples will include the use of general accounting equations (i.e., mass, energy, momentum and charge) toward problems from selected medical engineering fields.
Prerequisites: MATH 30650 (may be taken concurrently) or AME 30314 (may be taken concurrently) or MATH 34650 or AME 34314 or EGSC 34650

CBE 30399 Introduction to Unit Operations and Lab Procedures (Imperial) (0 Credit Hours)
Introduction to unit operations and lab procedures for the Imperial College, London summer study abroad program. Must be admitted to summer program for entry into course.

CBE 31358 Chemical Engineering Laboratory I (3 Credit Hours)
Chemical engineering laboratory courses are comprised of experiments that cover most of the major subject areas of chemical engineering. The rationale for combining all of the topics into two separate courses, as opposed to distributing them into the different lecture courses, is to provide a focused learning experience emphasizing experimental techniques to observe fundamental behavior, understanding of the phenomena in terms of the appropriate theory and experience at technical report writing. Formal and informal oral presentation skills are also an important part of the courses.
Satisfies the following University Core Requirements: WRIT - Writing Intensive
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 32338 Chemical Process Control Tutorial (0 Credit Hours)
Tutorial for Chemical Process Control.
Corequisites: CBE 30338

CBE 32356 Transport Phenomena II Tutorial (0 Credit Hours)
Tutorial for Transport Phenomena II.
Corequisites: CBE 30356

CBE 32361 Science of Engineering Materials - Tutorial (0 Credit Hours)
Tutorial for CBE 30361 Science of Engineering Materials
Corequisites: CBE 30361

CBE 32367 Chemical Engineering Thermodynamics II Tutorial (0 Credit Hours)
Tutorial for Chemical Engineering Thermodynamics CBE 30367
Corequisites: CBE 30367

CBE 32370 Phase Equilibria and Separations Tutorial (0 Credit Hours)
Tutorial for Phase Equilibria and Separations CBE 30370.
Corequisites: CBE 30370

CBE 34202 Biosystems & Bioprocessing Engineering (3 Credit Hours)
This course offers a comprehensive overview of the Biosystems and Bioprocess Engineering (BBE), which is an emerging field of applied research focused on understanding biological systems at a system-level in order to design and improve them for specific purposes. The BBE class covers various topics including systems and synthetic metabolic engineering approaches, as well as their industrial applications in the production of biomedicines, biochemicals, proteins, and platform/commodity chemicals. The course provides detailed information on background and manufacturing processes, including the selection and pre-treatment of raw materials, temperature/climate requirements, and fermentation conditions. By the end of this course, students will develop improved critical thinking skills to solve problems related to BBE. They will gain in-depth knowledge of biocatalyst-aided processes, microbial fermentation, protein purification, and the role of microbiomes in human health and wellness. Additionally, students will gain a deeper understanding of fermentation in the context of food and health, exploring perspectives and preferences related to genetic engineering, metabolic engineering, systems biology, and the design of novel biological processes. IR - Dublin, Ireland The aim of this module is for students to gain an understanding of the different commercial unit operations involved in downstream processing (DSP) from cell harvest to final purification and will enable students with the skills required to develop an appropriate purification strategy for different types and characteristics of biologics.

CBE 34315 Food Process Engineering (3 Credit Hours)
In this module you will study the application of heat and mass transfer, and reaction kinetic principles to a range of unit operations employed in the processing and preservation of food products. Specific topics covered will include drying, pasteurisation, aseptic processing, microwave and dielectric heating, crystallisation, evaporation, emulsification, process analytical technology and process simulations for equipment design. New and emerging technologies for the non thermal processing of foods and bioproducts (such a cold plasma processing) will be reviewed. Physical, chemical and microbiological changes which occur in foods during processing will also be studied. Specific case studies will be used to illustrate the processing technology presented in this module.

CBE 34337 Chemical and Pharmaceutical Unit Operations (3 Credit Hours)

Chemical processes (and Senior Design Projects) for antibodies, such as Alemtuzumab or commodity chemicals such as para-xylene are manufactured using a set of discrete operations that generally are not unique to the specific product. For example an affinity chromatography process for antibody purification has much in common with pressure swing adsorption for nitrogen production. These processes were categorized as Unit Operations, following Arthur D. Little (in 1916) and then codified by the textbook in 1923 by Walker, Lewis and McAdams. Chemical Engineering University curricula were largely organized around teaching these Unit Operations from the 1920's into the 1960's until advances in fundamental "scientific" understanding of the underlying fluid mechanics, heat transfer, mass transfer, thermodynamics and chemical kinetics with advances in computing led to the current "engineering science" curriculum. This course examines a selection of the most important Unit Operations that are used in chemical processing and pharmaceutical manufacturing. Examples are continuous contact separations processes (e.g., gas absorption, ion exchange, chromatography), staged separation processes (e.g., distillation), heat exchange (heat exchangers and cooling towers) fluid flow and mixing and some aspects of chemical reaction engineering. For each of the operations the "fundamental" phenomena will be described (since it is well known), but the detailed mathematical analysis of our Transport Phenomena classes will be bypassed to directly calculate, e.g., the number of stages, the total contacting area or length or the power needed for efficient mixing — so as to get a result for a key design question. Rising Juniors will find that the course material will motivate future study of phase equilibria, fluid flow, and heat and mass transfer. Rising seniors will acquire a new perspective on these topics and their utility. Both groups, repeating from above, will see how an understanding of the specific device combined with a process need, subject to various constraints, are used to design the devices that allow modern chemical and pharmaceutical manufacturing.

CBE 34338 Process Dynamics and Control (3-4 Credit Hours)

SI - Singapore This module presents the full complement of fundamental principles with clear application to heat exchangers, reactors, separation processes and storage systems. It incorporates introductory concepts, dynamic modeling, feedback control concepts and design methods, control hardware, and advanced control strategies including feed-forward, cascade and model-based control. SIMULINK will be introduced and used to simulate and examine the effectiveness of various control strategies. The module also incorporates case studies that prepare the students to design control systems for a realistic sized plant. This module is targeted at chemical engineering students who already have a basic knowledge of chemical engineering processes. HT - Hong Kong This course explores process modeling, including process variables such as input, output, manipulated variables, disturbances. Additionally, the course discusses mathematical modeling, degree of freedom and solutions. In the subject of process dynamics the course covers typical inputs and their Laplace transforms, first order, second order, higher order, model approximation, process delays and zeros and poles an their impact on dynamic responses. SY- Sydney, Australia Course that covers process dynamics and control of processes.

CBE 34356 Heat and Mass Transfer (3-4 Credit Hours)

This course considers three modes of heat transfer, namely, conduction, convection, and radiation. For heat conduction, both steady and unsteady states are examined. These are followed by analyses for convective heat transfer and heat transfer with phase change, and subsequently radiative heat transfer. Heat exchangers and their design are discussed. Steady and unsteady-state molecular diffusion is studied, while convective mass transfer is analyzed using exact and approximate integral analysis. Finally, analogies between mass, heat and momentum transfer are discussed leading to the concept of transport phenomena. SY - Sydney, Australia - University of Sydney This course considers mass transfer and heat transfer. This unit of study teaches principles of heat and mass transfer required for chemical and biomolecular engineering. It covers steady and transient conduction and diffusion, convective transport of heat and mass, and radiative heat transfer. It runs concurrently with CHNG2801 (Fluid Mechanics) to provide students with the tools and know-how to tackle engineering problems related to transport phenomena. This unit of study also includes project-based study components including a research project on heat transfer phenomena in biological systems and a lab session on mass transfer. Students will develop a physical understanding of the underlying phenomena and gain the ability to solve real heat and mass transfer problems of engineering significance.

CBE 34358 Biochemical Engineering Lab I (3 Credit Hours)

Students, working in pairs/groups, will undertake and report (via technical reports, posters and/or oral presentations) on selected experiments relating to the following topics: - Distillation: pilot-scale batch distillation with reflux, laboratory-scale solvent swap distillation - Fermentation: laboratory-scale batch yeast fermentation - Chromatography: chromatographic-based techniques for separation and/or analytical appications - Stirred Tank Reactors (STR): characterisation of mixing and mass transfer in standard configuration stirred tank reactors - Air-Lift Reactors (ALR): characterisation of hydroynamics and mixing in an air-lift reactor, operating in bubble colum and external-loop ALR mode. - Evaporation: performance of single-effect and triple-effect evaporation systems - Membrane filtration: water purification via osmosis.

CBE 34397 Chemical Engineering (design) topics (3 Credit Hours)

Good engineering practice produces quantitative results as we need them. But educationally, we want to understand how a device or process works even just to consider its possible use for a given application. Both of these questions fall under the broad category of "Design". In this class key fundamentals of heat transfer, fluid flow, mass transfer, and thermodynamics will be used to examine the various pieces of process equipment in the Imperial College pilot plant, to analyze "historic" technologies that can be seen in London museums and to determine if proposed "green energy" projects are likely to have a lower CO2 impact than existing technologies.

CBE 34487 Pharmaceutical and Bioprocessing Technology (3 Credit Hours)
UCD: This module deals with scientific, engineering and professional elements of commercial Pharmaceutical and Bioprocessing technology. Students will become familiar with the steps involved in both pharmaceutical and biopharmaceutical production, with a focus on key downstream unit operations like UF/MF and chromatography provided. The commercial production of insulin and insulin analogues in yeast and recombinant and conjugate vaccines in bacteria will be examined in detail. An overview of the production of biologics in mammalian cells will also be provided. Students will obtain a good grounding in the principles of bioreactor selection, design, scale-up and optimisation and will develop their ability to apply principles of mass transfer, fluid flow and heat transfer to bioreactor design and operation. Through a series of company presentations, students will become familiar with the importance of the Bio/Pharmaceutical sector to the Irish economy. Students will also be assisted in preparing to apply for Internship and Graduate positions within this sector.

CBE 34903 Heat Transfer and Fluid Mechanics (3 Credit Hours)
This module will introduce students to the principles of heat transfer and fluid mechanics with particular emphasis on applications in chemical and process engineering systems. Students will learn how how to apply the principles of heat transfer and fluid mechanics as part of basic chemical process design focusing on flows through process equipment, heat exchangers, piping systems, pumping applications. *Students may elect for this course to satisfy CBE 30356 Transport 2.

CBE 40020 Energy Transition to a Sustainable Future (3 Credit Hours)
A survey course on all aspects of the transition from fossil fuels to more sustainable energy resources. This will include an understanding of 1) current energy production and use, 2) the importance of light hydrocarbons as a bridge to a net-zero carbon economy, 3) the environmental implications of energy production and storage, 4) carbon capture, sequestration, and conversion, 5) the role that electrification plays in the transition, and 6) sources of low-CO2 footprint energy necessary to achieve a sustainable energy future.

CBE 40325 Immunoengineering (3 Credit Hours)
The immune system involves the most complex yet most powerful processes in the human body to protect us from both invading foreign pathogens and self-derived challenges. As the basic understanding of immunology is growing, engineers are rapidly designing intelligent and diverse strategies to manipulate the immune system to improve human health. In this course, we will extensively cover the basic concepts of immunology as well as explore the engineering strategies currently used to harness the power of the immune function to develop therapeutic and diagnostic approaches for improved human health.
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 40361 Advanced biomolecular and physiological thermodynamics (3 Credit Hours)
This course will use fundamental principles of thermodynamics, as contained in a first thermo course for chemical engineers and generalize“chemical thermodynamics” — phase equilibria, chemical equilibria, and chemical binding, to biochemical thermodynamics which would include charged systems, polymers, and biochemical ligands. This motivates membranes and membrane transport… which leads to molecular-level processes of cells as well as nerve signal transduction and other physiological applications. This will be about 2/3 of the course.

CBE 40425 Energy, Economics, and Environment (3 Credit Hours)
Energy, economics, and the environment are irrefutably linked. Many new energy technologies are under development to meet our future needs, as current sources of energy may increase in cost with increased global demand or have undesirable environmental consequences. This course will review current and emerging primary energy sources and energy technologies in three areas: electricity generation and use, transportation, and heating and cooling. A significant focus of the course will be on alternative energy technologies. Energy related practices and technologies will be quantitatively compared. This course requires active student participation.
Enrollment is limited to students with a major in Chemical Engineering.

CBE 40430 Industrial Chemical Processes (3 Credit Hours)
The chemical industry is responsible for products and processes that account for nearly 25% of America’s GDP. In fact, the industry touches nearly every sector of our economy including agriculture, construction, technology, manufacturing, and retail trade, and is responsible for nearly seven million American jobs. This course examines the characteristics and commercial manufacturing processes of many of the key chemicals that are critical to our quality of life. The course will examine the global market drivers and major innovations that motivated the large scale production of these chemicals. It will also trace the history of several of the major chemical companies that evolved along with the markets for these chemicals. Case studies will be used to describe how discoveries are translated into major commercial chemical process and product innovations.
Enrollment is limited to students with a major in Chemical Engineering.

CBE 40434 Batteries and Fuel Cells (3 Credit Hours)
In this class, students learn the fundamental theoretical concepts underlying electrochemical systems, but do not learn how these concepts govern the function of engineered electrochemical systems. This course combines the study of charge transfer at electrode/electrolyte interfaces with the development of practical materials and processes. The development of the technology involves the study of the electrochemical reactors, their voltage and current distribution, mass transport conditions, hydrodynamics, geometry as well as the quantification of overall performance in terms of reaction yield, conversion efficiency, and energy efficiency. This course examines the operational principles of electrochemical energy storage devices (batteries and capacitors), energy conversion devices (fuel cells, electrolyzers), electrodeposition, corrosion, and bioelectrochemical interfaces. The emphasis is on materials and device design based on fundamental chemistry and physics concepts that govern the properties and performance of the materials/devices involved. Specific systems of study will include electrode and electrolyte materials for primary (non-rechargeable) and secondary (rechargeable) batteries including lithium-ion batteries, electrochemical capacitors, proton exchange membrane fuel cells, solid oxide fuel cells, alloy electrocatalysts, mixed ionic-electric conductors, and biosensor development.

CBE 40435 Electrochemistry and Electrochemical Engineering (3 Credit Hours)
This course addresses the fundamentals and applications of technologies that rely on heterogeneous electron transfer reactions. The first part of the course addresses fundamental aspects of electron transfer reactions at electrified interfaces, including band structure of metals and semiconductors, electrochemical potentials, electron transfer kinetics and Marcus theory, potential step and potential sweep experiments, hydrodynamic electrochemistry, potentiometry and ion-selective electrodes, impedance measurements, and electrochemical instrumentation. The second part of the course addresses applications to energy storage (batteries, fuel cells, supercapacitors), energy conversion (photovoltaics), bioelectrochemistry, including neurochemistry, corrosion, and electrolysis and electroplating.
Prerequisites: CBE 20260 and CBE 30367 or CHEM 30321 and CHEM 30322

CBE 40443 Separation Processes (3 Credit Hours)
This course demonstrates the application of the principles of phase equilibria, transport processes, and chemical kinetics to the design and characterization of stagewise and continuous separation processes. Both graphical and rigorous numerical techniques are used, and the general procedures applicable to different specific processes are emphasized. Example problems are drawn from the petroleum, chemical, food, biochemical, and electronic materials processing industries. The AspenONE software package is used.
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 40445 Chemical Reaction Engineering (3 Credit Hours)
The basic concepts of chemical rate processes are applied to the theory of the design and operation of the various types of commercial reactors for both noncatalytic and catalytic reactions. Topics covered include mole balances, rate laws and stoichiometry, collection and analysis of rate data, multiple reactions, isothermal and nonisothermal reactor design, catalysis and catalytic reactors.

CBE 40448 Chemical Process Design (3 Credit Hours)
This course represents a capstone in the chemical engineering curriculum. In this course students will have the opportunity to apply the basic concepts learned in previous courses to the design and analysis of a chemical processing system. This will be done primarily through the design project. Supporting material to be covered in lectures includes the following: computer-aided design (process simulation), economic analysis, process safety, flowsheet synthesis (conceptual design), and decision-making analysis (optimization). The AspenONE software package is used.
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 40455 Process Operations (3 Credit Hours)
This class covers the biological and engineering aspects of drug discovery and development, and pharmacology, with an emphasis on drug-receptor interactions and mechanism of action for therapeutic outcomes. Pharmacokinetics, pharmacodynamics, metabolism, and toxicity as a basis for drug development are also covered.
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 40456 Polymer Engineering (3 Credit Hours)
A course for seniors and graduate students in science and engineering who are interested in applications of engineering to polymer science and technology. Topics include polymerization reactions and the structure, properties, processing, and production of polymers. (Every year)
Prerequisites: (CBE 30356 and CBE 30367) or CBE 30370
Enrollment limited to students in the College of Engineering or College of Science colleges.

CBE 40457 Polymer Science and Engineering (3 Credit Hours)
This course is an intermediate level introduction to the fundamental chemistry and physics of polymer materials. The course is designed to meet the needs of students in all science and engineering disciplines who are interested, or already engaging in polymer related research. The lectures will focus on the underlying concepts and principles in polymer materials, emphasizing the interrelationships between synthesis, structure, processing, properties and performance, and demonstrate them in the context of their everyday use as well as real-world advanced engineering applications. Major topics in polymer chemistry, physics and engineering will be covered including: general introduction of polymers, major classes of polymerization reactions and kinetics, microstructure and morphology, polymer properties (thermal, mechanical, etc.), polymer thermodynamics, polymer characterization techniques, and plastics engineering and processing methods. The successful students will emerge from the course with a current, sound knowledge of polymer concepts and an ability to apply them in career situations.
Prerequisites: CBE 30361 and CBE 30367 and CHEM 30324

CBE 40475 Molecular Modeling and Simulation (3 Credit Hours)
An introduction to the theory, methods, and applications of molecular modeling and simulation as applied to contemporary research in chemistry, chemical engineering, physics, and biology. Topics include elementary statistical mechanics and ensemble theory, classical force fields, Monte Carlo, molecular dynamics, quantum mechanical simulations, free energy calculation, and simulation of thermodynamic and transport properties. Application areas include simple and complex fluids as well as solids.

CBE 40477 Nanoscience and Technology (3 Credit Hours)
This course focuses on the unique scientific phenomena that accrue to matter with characteristic nanometer-scale dimensions and on the technologies which can be constructed from them. Special optical, electronic, magnetic, fluidic, structural and dynamic properties characteristic of nanostructures will be addressed.
Prerequisites: CHEM 30321 or CHEM 30324

CBE 40479 Introduction to Cellular and Tissue Engineering (3 Credit Hours)
This course is divided into two parts. The first half will cover principles of cell and developmental biology that guide current approaches in tissue engineering and regenerative medicine. An emphasis will be placed on the computational and quantitative analysis of biological processes such as cell-cell signaling and morphogenesis. The second half covers techniques involved in cultivating cells for applications in recombinant protein production as well as the design of bioartificial organs and regenerative therapeutics. Optimization techniques for culture medium development will also be covered.
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 40483 Topics in Biomolecular Engineering (3 Credit Hours)
The objective of this class, intended for both upper level undergraduate and graduate students, is to illustrate the emerging field of bioengineering which fuses molecular life sciences with engineering. The students will gain a fundamental understanding in the principles of how biological systems function, and learn about the innovative approaches that engineers take for diagnosis, treatment, and prevention of diseases, design of novel materials, devices, and processes, and in enhancing environmental health. Topics will include: Biological systems, Cell functions, Molecular scale (what is nano?), Molecular interactions & Multivalency, Synthetic molecules, Molecular biology, -Fermentation, Cell culture, & Combinatorial methods-,Protein purification, Bioinformatics, Biotechnology, Biomedical engineering, Drug delivery, Biosensors
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 40487 Drug Development and Pharmacology (3 Credit Hours)
This class covers the biological and engineering aspects of drug development, production, and mode of action.

CBE 40499 Nonlinear and Stochastic Optimization (3 Credit Hours)
This course will provide a practical introduction to algorithms, formulations, and modern software for large-scale numerical optimization. Topics include (nonconvex) nonlinear programming, deterministic global optimization, integer programming, dynamic optimization, and stochastic programming. Multi-objective optimization and mathematical programs with complementarity constraints may be covered based on time and student interests. The target audience for is graduate students from engineering, science, and mathematics who wish to incorporate optimization methods into their research. The course will begin with a concise introduction to optimization theory and algorithms. Problem formulation and use of state-of-the-art solvers and modeling environments will be emphasized throughout the course. A background in linear algebra and numerical methods will be helpful but is not necessary. Students should be comfortable programming in Julia, Python, MATLAB, C, or a similar language. EE 60551: Mathematical Programming is not a prerequisite for this course.

CBE 40501 Machine Learning for Chemical Engineers (3 Credit Hours)
Machine Learning (ML) is an important technological tool affecting society in myriad ways. Chemical engineering is not the exception. Students will be exposed to multiple examples within the chemical engineering discipline to appreciate the potential of ML as well as its limitations. The course is structured to provide a practical introduction to machine learning for chemical engineers. Topics to be covered include regression, supervised learning, unsupervised learning, feature extraction and other tools relevant to chemical and molecular engineering (SMILES, RDKit, etc.). The course will emphasize practical programming skills using Python implementations and will use case studies in chemical engineering. Students should have strong math and Python skills. Students who have already taken classes such as Numerical Methods and Statistical Analysis, Linear Algebra, Calculus, and Thermodynamics should have the necessary background to be successful in this course.

CBE 40525 Ambient Methods for Surface Characterization (3 Credit Hours)
Ambient Methods for Surface Characterization. This course develops fundamental principles for characterizing surfaces and interfaces, particularly thin films, using infrared spectroscopy, ellipsometry, electrochemistry, and contact angle measurements. The material will cover reflection of light from surfaces, which is relevant to surface infrared spectroscopy, surface plasmon resonance and ellipsometry, surface energies, adsorption isotherms, and some fundamental aspects of electrical double layers, zeta potentials, and mass transport in electrochemistry.

CBE 40571 Biomaterials (3 Credit Hours)
This course focuses on the fundamental principle of biomaterials, the interaction of biomaterials with the biological system, and applications of biomaterials. Topics include molecular principles of biomaterials, cell-biomaterials interaction, host reaction to biomaterials, biomaterials for tissue engineering applications, and biomaterials for controlled drug delivery. Historic and nascent advances in biomaterials are critically and independently evaluated by the class using published reports in the literature. Clinical, business, and regulatory perspectives of biomaterials will be discussed using case studies and group projects.

CBE 40623 Surface Science (3 Credit Hours)
This course covers the structure and properties of solid surfaces and interfaces and the dynamics of chemical reactions at surfaces. Topics include geometrical structure, surface morphology, electronic structure, surface composition, kinetics and dynamics (adsorption, scattering, vibrations, diffusion, desorption), structure and reactivity of surface molecules, non-thermal excitations of surfaces, and modern ultrahigh vacuum experimental techniques.

CBE 40698 Dynamics of Structured Fluids (3 Credit Hours)
This course is designed to introduce students to the fundamentals of colloidal suspensions and their rheological behavior. Phenomena explored include electrostatics, dispersion forces, flocculation, and non-Newtonian rheology.

CBE 40725 Principles of Molecular Engineering (3 Credit Hours)
The objective of this course, intended for both upper level undergraduate and graduate students, is to illustrate the emerging field of molecular engineering. By fusing concepts from chemistry and materials science, molecular engineering seeks rational design of chemical building blocks for organized systems and materials. Students will gain a fundamental perspective for how non-covalent interactions and designed molecular motifs can dictate the structure, function, and properties of resulting engineered systems. This will include an appreciation for the role on intermolecular forces in governing the behavior of these molecules as they interact with each other and with their environment (typically a solvent). Additionally, illustrative examples will point to the power of strategies rooted in principles of molecular engineering to create highly controlled and functional materials. topics will include: non-covalent interactions, molecular design, thermodynamic driving forces, solvent effects, molecular self-assembly, supramolecular chemistry, molecular & materials characterization techniques, and applications of molecular engineering for diverse uses in energy, medicine, computing, formulation science, industrial applications, and food sciences.

CBE 40730 Materials Characterization for Soft and Polymeric Materials (3 Credit Hours)
This course will provide a comprehensive introduction to advanced materials characterization techniques, with a focus on soft matter and polymeric systems. Topics covered include electron microscopy techniques such as transmission electron microscopy (TEM) with complementary cryogenic (CryoEM) and in situ (liquid phase EM), scanning electron microscopy (SEM), environmental scanning electron microscopy (ESEM), tomographic reconstructions/tilt series, and image processing methods, along with sample preparation strategies. Fundamentals of electron optics and electron-specimen interactions will be discussed, including elastic and inelastic scattering techniques such as energy-dispersive spectroscopy (EDS) and electron energy loss spectroscopy (EELS). The course will also explore advanced scattering methods, including X-ray and neutron scattering and diffraction, to investigate polymer amorphous, crystalline, and nanostructures. Various microscopy techniques, including polarized light microscopy (POM), and atomic force microscopy (AFM), will be covered to analyze material morphology and properties. Thermal analysis methods, such as traditional, modulated, and flash differential scanning calorimetry (DSC/MDSC/flash DSC), thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA), and polymer rheology will be presented to understand polymer metastability, thermal behavior, thermomechanical properties. Students will learn to integrate these techniques into the design of experiments for targeted applications, with an emphasis on in-situ characterization, error quantification, and the practical challenges of characterizing complex systems. Finally, materials characterization and safety standards (ASTM/ISO), and respective regulating bodies will be introduced to bridge the technical, practicality, and reproducibility gaps that can exist between traditional academic research and industrial scale research & development on a national and international scale.

CBE 40731 Nanomedicine: Therapeutics and Diagnostics (3 Credit Hours)
This course focuses on understanding the central role of nanotechnology in the development of new therapeutic and diagnostic tools that can be used for the detection, imaging, and treatment of different life-threatening diseases. The course will review the basic knowledge and engineering principles of nanomedicine ranged from fundamental properties, synthesis, and characterization of nanomaterials to the laws revolved around molecular and particulate transport, sorting and binding. Based on this foundation, the course will discuss 1) specific examples of nanotechnology applications in therapeutics such as drug and vaccine delivery; 2) formulation of nanostructured devices and their application in diagnostic and imaging; 3) translation from concept to the clinic and commercialization.

CBE 40743 Materials Engineering and Manufacturing of Sports Equipment (3 Credit Hours)
Advanced materials and the associated manufacturing processes have led to significant performance advances in a range of sports. This course will examine the science behind the materials utilized in advanced sports equipment and how the equipment is manufactured. Properties of wood, metals and composites will be reviewed and compared. Production of carbon and glass fibers will be discussed. Concepts in materials selection (Ashby diagrams) will be introduced. Advanced materials that have been utilized in sports equipment including shape memory alloys and piezoelectrics will be examined. Specific examples of sports equipment development where materials have revolutionized performance will be studied in detail, including tennis rackets, golf clubs, downhill skis, vaulting poles and running shoes. The ethics of the use of ever improving equipment will also be discussed. At the end of the semester students will present review studies on other advanced sports equipment of their choosing (e.g. swim suits, baseball bats, golf balls, etc).

CBE 40888 Cellular and Physical Principals of Bioengineering (3 Credit Hours)
This course covers the breakdown of biological systems at molecular, cellular and tissue levels. It evolves to the design and synthesis of biomaterials at a molecular scale used in manipulating and targeting biological systems, including biotechnology and biomedical engineering. For these purposes, we will learn what is inside a cell, molecular machines, nerve impulses, binding thermodynamics and kinetics in biological systems, chemical forces and molecular self-assembly.

CBE 40910 Biomolecular Engineering Lab Lecture (0 Credit Hours)
In this course, students are exposed to modern laboratory methods in bioengineering and experimental design. Students gain the knowledge to; develop and execute laboratory protocols, write laboratory reports, and present orally their findings. Space in the lab is limited to 32 students. Students with bio and pre-med interests are given priority. If necessary, students are selected through an application process conducted prior to senior registration. All rising senior CBE students are notified via email of the required application and due date.
Corequisites: CBE 41910

CBE 41459 Chemical Engineering Laboratory II (3 Credit Hours)
Chemical engineering laboratory courses are composed of experiments that cover most of the major subject areas of chemical engineering. The rationale for combining all of the topics into two separate courses, as opposed to distributing them into the different lecture courses, is to provide a focused learning experience emphasizing experimental techniques to observe fundamental behavior, understanding of the phenomena in terms of the appropriate theory and experience at technical report writing. Formal and informal oral presentation skills are also an important part of the courses.

CBE 41622 Laboratory Measurement and Instrumentation for Chemical Engineers (3 Credit Hours)
A practical overview of the theory, methods, hardware, and software for routine laboratory measurements used in chemical and biomolecular engineering research. The course introduces students to embedded systems based on Arduino and Raspberry Pi hardware, basic sensors, network protocols for logging data and integrating with services, interfacing with experiments, signal conditioning, anomaly detection, and the theory of measurements. Students will work extensively with hardware. Completing a significant project is an integral element of the course. Experience with coding and scripting languages is required. Minimal knowledge or experience with electronics is assumed.

CBE 41910 Biomolecular Engineering Lab (3 Credit Hours)
In this course, students are exposed to modern laboratory methods in bioengineering and experimental design. Students gain the knowledge to; develop and execute laboratory protocols, write laboratory reports, and present orally their findings. Space in the lab is limited to 32 students. Students with bio and pre-med interests are given priority. If necessary, students are selected through an application process conducted prior to senior registration. All rising senior CBE students are notified via email of the required application and due date.
Corequisites: CBE 40910
Enrollment limited to students in the Chemical & Biomolecular Engr. department.

CBE 42448 Process Design Tutorial (0 Credit Hours)
Tutorial for CBE 40448 Process Design
Corequisites: CBE 40448

CBE 44360 Plant Operations - Imperial College (3 Credit Hours)
In this course, students will gain hands-on experience in the operation, design and control of a working chemical plant. The course is taught at Imperial College, London and features a fully instrumented 4-story anime-based CO2 capture plant. Students will operate the plant from a remote control room, use piping and instrumentation diagrams to identity equipment and trace flows, troubleshoot the plant to correct problems, and gain firsthand knowledge of process safety and operations
Enrollment is limited to students with a major in Chemical Engineering.

CBE 44479 Cell Culture & Tissue Eng (3 Credit Hours)
This module will provide students with an understanding of the principles and techniques involved in cell culture and tissue engineering. This module will examine the basic biological characteristics and behaviour of both embryonic and adult stem cells. This module will examine the techniques involved in culturing stem cells for both research and clinical purposes. The techniques involved in expanding cells for cell therapy purposes and engineering of tissues, organs and in vitro systems will also be examined. The ethical and legal problems associated with tissue engineering and cell therapy as an emerging therapy will also be discussed.

CBE 44488 Principles of Biopharmaceutical Engineering (3 Credit Hours)
On completion of this module students should be able to: 1. Describe in qualitative terms the operation of a variety of biopharmaceutical process operations. 2. Manipulate and perform calculations on process variables with particular emphasis on data analysis and evaluation. 3. Apply unsteady-state mass and energy balance concepts to batch, fed batch and continuous processes. 4. Perform simple performance evaluation and design calculations for a variety of rate-controlled process equipment. Indicative Module Content: Some of the topics are: Mass and Energy Balances Steady and Unsteady Systems Mixing Mass Transfer Aeration

CBE 44999 Undergrad Research Experience (0 Credit Hours)
This is a zero-credit course for students engaged in independent research or working with a faculty member of the University on a special project while remote. No course work is required.

CBE 46497 Directed Readings (1-3 Credit Hours)
Course requires the student to explore various readings chosen by the professor.
Course may be repeated.

CBE 47099 Special Studies (0-3 Credit Hours)
Small group or individual study in an undergraduate subject not offered by a University course or not offered in the semester needed. The student or group of students is directed by a faculty member.

CBE 48901 Undergraduate Research (1 Credit Hour)
This is the course that students should sign up for as their first experience in research. This is a one credit course, and involves a minimum commitment of 4-5 hours/wk. This course is S/U, may be taken more than once, but does not satisfy the Engineering/technical elective degree requirement.
Course may be repeated.

CBE 48902 Advanced UG Research (3 Credit Hours)
This is a three credit course on which students should expect to spend 12-15 hours per week. Successful completion of CBE 48901 or a summer (or academic year) research internship in the Department is a prerequisite for enrolling in CBE 48902. It can be counted as an Engineering/technical elective and students must produce a written report of their results at the end of the semester. This course is graded, and may be repeated.
Prerequisites: CBE 48901
Course may be repeated.

CBE 48903 Undergraduate Thesis (3 Credit Hours)
This is a three credit course which is normally taken in the final semester. Successful completion of CBE 48901, CBE 48902 or a summer (or academic year) research internship in the Department is a prerequisite for enrolling in CBE 48903. Students are required to produce a substantial written document that will be defended orally to a committee of CBE faculty. This course can be counted as a (3 credit) CBE elective, and may not be repeated.
Prerequisites: CBE 48902

CBE 48999 Undergraduate Research Experience (0 Credit Hours)
Registrar: This is a zero-credit course for students engaged in independent research or working with a faculty member of the University on a special project. No course work is required.