06-100 Introduction to Chemical Engineering
Fall and Spring: 12 units
We equip students with creative engineering problem-solving techniques and fundamental chemical engineering material balance skills. Lectures, laboratory experiments, and recitation sessions are designed to coordinate training and experience in data analysis, material property estimation for single- and multi-phase systems, basic process flowsheet, reactive and non-reactive mass balances, problem solving strategies and tools, and team dynamics. The course is targeted for CIT First Year students.

06-200 Sophomore Research Project
Fall and Spring
Research projects under the direction of the Chemical Engineering faculty. The nature of the project, the number of units, and the criteria for grading are to be determined between the student and the faculty supervisor. The agreement should then be summarized in a one-page project description for review by the faculty advisor of the student. A final written report or an oral presentation of the results is required.

06-221 Thermodynamics
Fall: 9 units
This course introduces students to the process thermodynamics of single component systems. Topics include equilibrium and thermodynamic state variables; heat and work; conservation of energy and the first law of thermodynamics; entropy and the second law of thermodynamics; reversibility; free energies; interconversion of heat and work via engines, refrigeration and power cycles; absolute temperature and the third law of thermodynamics; equations of state; principle of corresponding states; thermodynamic property relationships; changes of state; phase equilibrium and stability in single component systems; vapor pressure and phase transition.
Prerequisites: (33-106 and 06-100) or (06-100 and 33-141) or (33-151 and 06-100) or (06-100 and 33-121)

06-222 Sophomore Chemical Engineering Seminar
Fall: 1 unit
This course provides an overview of the chemical engineering profession. It discusses the rationale for the curriculum, career paths, resume writing, written communication skills, and ethics, and also involves a project on the use and manufacture of chemicals.

06-223 Chemical Engineering Thermodynamics
Fall: 12 units
This course introduces students to thermodynamic state variables and the analysis of phase and chemical equilibrium in single- and multi-component chemical systems. Key topics include application of mass, energy and entropy balance equations to analyze processes with change of state and interconversion of energy between heat and work in open or closed systems; state property changes associated with phase change; equations of state to represent the pressure-volume-temperature relationship for pure materials and mixtures; Gibbs phase rule; phase equilibrium criteria; ideal and non-ideal mixtures; fugacity and prediction of pure liquid vapor pressure; fugacity and activity coefficients to predict multi-component vapor-liquid and liquid-liquid phase equilibrium; analysis of flash and other processes involving multi-component phase change; equilibrium constants and equilibrium conversions in chemically reacting systems.
Prerequisites: 06-100 and (33-121 or 33-141 or 33-151)

06-261 Fluid Mechanics
Spring: 9 units
The principles of fluid mechanics as applied to engineering, including unit operations, are discussed; examples include flow in conduits, process equipment, and commercial pipes, flow around submerged objects, and flow measurement. Microscopic mass and momentum balances are described, including the continuity and Navier-Stokes equations, and modern solution techniques will be explored. Microscopic flow structures will be determined for flow visualization. Boundary layer theory, turbulence, and non-Newtonian fluids are also discussed. A case-study project based on new technological advancements is also required.
Prerequisites: (21-259 or 21-254) and (33-151 or 33-141 or 33-121 or 33-106)

06-262 Mathematical Methods of Chemical Engineering
Spring: 12 units
Mathematical techniques are presented as tools for modeling and solving engineering problems. Modeling of steady-state mass and energy balance problems using linear and matrix algebra, including Gaussian elimination, decomposition, and iterative techniques. Modeling of unsteady-state engineering problems using systems of linear and nonlinear differential equations. Analytical techniques, including Laplace transforms, and numerical techniques for the solution of first- and higher-order differential equations and systems of differential equations arising in engineering models. Finally, the modeling of processes affected by chance and subject to experimental error; statistical and regression techniques within the context of experimental design and analysis of experimental data.
Prerequisites: 06-100 and 21-122 Min. grade C and 06-221

06-300 Junior Research Project
Fall and Spring
Research projects under the direction of the Chemical Engineering faculty. The nature of the project, the number of units, and the criteria for grading are to be determined between the student and the faculty supervisor. The agreement should then be summarized in a one-page project description for review by the faculty advisor of the student. A final written report or an oral presentation of the results is required.

06-310 Molecular Foundations of Chemical Engineering
Fall: 9 units
Students will learn to use the tools of molecular engineering to define the modern development of chemical engineering, using a combination of theory and computation. The theme throughout the course is the use of molecular engineering tools to specify alternative compositions and conditions for chemical engineering design. Applications will include the prediction of macroscopic transport properties and equations of state, and the ability to tune them via judicious specification of system composition; rate laws and rate constants for complex reacting systems, including multi-step heterogeneous and homogeneous reactions; and principles of non-covalent association and self-assembly in the context of sustainable chemical engineering product design. Students will investigate contemporary molecular engineering case studies focused on renewable energy, human health or solutions to environmental problems.
Prerequisite: 06-223

06-321 Chemical Engineering Thermodynamics
Fall: 9 units
The objective of this course is to cover principles and solution techniques for phase and chemical equilibria in multicomponent systems. Topics include thermodynamic properties of ideal and non-ideal mixtures; criteria for equilibrium; chemical potential, fugacity and activity coefficients; flash calculations; Gibbs energy minimization; thermodynamics of chemical reactions including equilibrium conversions.
Prerequisite: 06-221

06-322 Junior Chemical Engineering Seminar
Fall: 2 units
This course discusses career choices for chemical engineers, professional practice, including alternate career paths, global industry, and graduate studies. It also emphasizes writing, interview skills, and oral presentations. Safety, environmental and ethical issues are illustrated in projects and via invited lectures.
06-323 Heat and Mass Transfer  
Fall: 9 units  
This course presents the fundamentals of heat and mass transfer, including steady-state and transient heat conduction and molecular diffusion, convection of heat and mass, and thermal radiation, with application to heat and mass transfer processes. Development of dimensionless quantities for engineering analysis is emphasized.  
Prerequisites: 06-261 and (06-262 or 21-260)

06-325 Numerical Methods and Machine Learning for Chemical Engineering  
Fall: 6 units  
This course will focus on applying numerical methods and machine learning to chemical engineering problems. Students will learn how modern programming environments (on laptops and in the cloud) can run python code. Programming concepts such as defining functions and plotting quantities will be reviewed. Students will learn how to apply and debug numerical integration techniques to systems of ODEs. Solving systems of nonlinear equations and black-box optimization will be covered. Machine learning will be introduced starting with the statistics of linear and non-linear regression with regularization. Polynomial fitting and interpolation will be covered. With this base, students will learn how to apply machine learning techniques such as gaussian process regression and neural networks to regression tasks. A small project will be included near the end to encourage creative applications to chemical engineering problems.  
Prerequisites: 06-262 Min. grade C and (15-110 or 15-112)

06-326 Optimization Modeling and Algorithms  
Fall: 6 units  
Formulation and solution of mathematical optimization problems with and without constraints. Objective functions are based on economics or functional specifications. Both discrete and continuous variables are considered.  
Prerequisite: 06-223

06-361 Unit Operations of Chemical Engineering  
Spring: 9 units  
This course comprises many of the standard operations in chemical plants such as gas absorption, heat exchange, distillation and extraction. The design and operation of these devices is emphasized. A project dealing with a novel unit operation is also investigated.  
Prerequisites: 06-323 and 06-321

06-363 Transport Process Laboratory  
Spring: 9 units  
Develop skills for proposing, designing, planning, implementing, interpreting, and communicating the results of experiments in fluid flow and heat and mass transfer. Oral and written reports are required.  
Prerequisites: 06-261 and 06-323

06-364 Chemical Reaction Engineering  
Spring: 9 units  
Fundamental concepts in the kinetic modeling of chemical reactions, the treatment and analysis of rate data. Multiple reactions and reaction mechanisms. Analysis and design of ideal and non-ideal reactor systems. Energy effects and mass transfer in reactor systems. Introductory principles in heterogeneous catalysis.  
Prerequisites: 09-347 and 06-323 and 06-321

06-400 Senior Research Project  
Fall and Spring  
Research projects under the direction of the Chemical Engineering faculty. The nature of the project, the number of units, and the criteria for grading are to be determined between the student and the faculty supervisor. The agreement should then be summarized in a one-page project description for review by the faculty advisor of the student. A final written report or an oral presentation of the results is required.

06-421 Chemical Process Systems Design  
Fall: 12 units  
Prerequisites: 06-364 and 06-321 and 06-361

06-423 Unit Operations Laboratory  
Fall: 9 units  
Open-ended laboratory projects illustrate the principles of unit operations in Chemical Engineering. In this course students select, with course staff review, current societal problems to which chemical engineering subject knowledge can be applied. Students work in teams to design and implement an experimental plan to evaluate proposed solutions. Teams must work together to identify constraints and relationships between the unit operations they work on. Students must document implementation feasibility (cost, scheduling, analytic capability, etc.) and clearly identify the criteria and methods for assessing experimental results. Oral and written reports are required.  
Prerequisites: 06-361 and 06-364

06-426 Experimental Colloid Surface Science  
Fall: 9 units  
Laboratory exercises will deal with preparation and stabilization of colloids, flocculation, micellar aggregates, surface tension, contact angle, spreading and adsorption. Basic concepts will be related to practical problems of wetting, lubrication, foaming, adhesion, coatings and corrosion.  
Prerequisites: 06-607 and 09-221

06-462 Optimization Modeling and Algorithms  
Spring: 6 units  
Formulation and solution of mathematical optimization problems with and without constraints. Objective functions are based on economics or functional specifications. Both discrete and continuous variables are considered.  
Prerequisite: 06-421

06-463 Chemical Product Design  
Spring: 6 units  
Computer-aided design of a chemical product. Course involves design of molecular structure, microstructure, or devices/processes that effect chemical change. This is a project-based course, for which an extensive report must be submitted.  
Prerequisite: 06-421

06-464 Chemical Engineering Process Control  
Spring: 9 units  
This course presents basic concepts of process dynamics and feedback control. Included are selection of measurements and manipulated variables, definition of transfer functions, creation of block diagrams and closed loop configurations. The course also covers concepts of open loop and closed loop stability, and tuning of PID controllers.  
Prerequisite: 06-262

06-466 Experimental Polymer Science  
Spring: 9 units  
Macromolecular behavior in bulk and in solution will be explored in experiments on tensile strength, elasticity, swelling of networks, solution viscosity, melt flow, and polymerization reactions. Particular reference will be made to aspects affecting production and fabrication of polymeric materials.  
Prerequisites: 09-221 and (09-509 or 06-609)

06-606 Computational Methods for Large Scale Process Design & Analysis  
Spring: 9 units  
This course deals with the underlying computer-aided design techniques for steady-state and dynamic simulation, numerical solution and decomposition strategies for large systems of sparse nonlinear algebraic equations, stiff ordinary differential equations, strategies for mixed algebraic/differential systems and computer architectures for flowsheeting systems.  
Prerequisites: 06-262 and 06-361

Course Website: http://numero.cheme.cmu.edu/course/06606.html

06-607 Physical Chemistry of Colloids and Surfaces  
All Semesters: 9 units  
Thermodynamics of surfaces; adsorption at gas, liquid, and solid interfaces; capillarity; wetting, spreading, lubrication and adhesion; properties of monolayers and thin films; preparation and characterization of colloids; colloidal stability, flocculation kinetics, micelles, electrokinetic phenomena and emulsions.  
Prerequisite: 06-221
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>06-608</td>
<td>Graduate Professional Development Seminar</td>
<td>3</td>
<td>This course will also expose the students to personal safety issues encountered in normal science and engineering practice. Safety topics covered include mechanical, electrical, chemical, radiation, and biological hazards, to provide an awareness of these hazards and appropriate action to be taken in the event of an accident.</td>
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<tr>
<td>06-609</td>
<td>Physical Chemistry of Macromolecules</td>
<td>9</td>
<td>This course develops fundamental principles of polymer science. Emphasis is placed on physio-chemical concepts associated with the macromolecular nature of polymeric materials. Engineering aspects of the physical, mechanical and chemical properties of these materials are discussed in relation to molecular structure. Topics include an introduction to polymer science and a general discussion of commercially important polymers, molecular weight; condensation and addition synthesis mechanisms with emphasis on molecular weight distribution; solution thermodynamics and molecular conformation; rubber elasticity; and the rheological and mechanical properties of polymeric systems. Students not having the prerequisite listed may seek permission of the instructor.</td>
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<tr>
<td>06-610</td>
<td>Rheology and Structure of Complex Fluids</td>
<td>9</td>
<td>This course will cover the basic concepts of rheology and mechanical behavior of fluid systems. Both the experimental and theoretical aspects of rheology will be discussed. The basic forces influencing complex fluid rheology and rheology will be outlined and discussed; including excluded volume, van der Waals, electrostatic and other interactions. Methods of characterizing structure will be covered including scattering techniques, optical polarimetry and microscopy. Examples will focus on several types of complex fluids including polymer solutions and melts, gelling systems, suspensions and self-assembling fluids.</td>
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<tr>
<td>06-612</td>
<td>Formulation Engineering</td>
<td>12</td>
<td>Students will learn the scientific and design principles needed for careers in complex fluid formulation-based industries such as consumer products, pharmaceuticals, paints, agrochemicals or lubricants. The essential science and engineering principles of colloids, surfactants, interfaces and polymer solutions will be introduced. Students will learn to use these principles in combination with experimental measurements and statistical design of experiments tools to design effective liquid product formulations within specified economic, material and even aesthetic constraints. The lecture portion of the course is complemented by weekly lab sessions where student teams will design and improve their own formulations for a commercial complex fluid product, such as a detergent or an ink, that meets performance goals within specified constraints.</td>
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<tr>
<td>06-622</td>
<td>Bioprocess Design</td>
<td>9</td>
<td>This course is designed to link concepts of cell culture, bioseparations, formulation and delivery together for the commercial production and use of biologically-based pharmaceuticals; products considered include proteins, nucleic acids, and fermentation-derived fine chemicals. Associated regulatory issues and biotech industry case studies are also included. A fair knowledge of cell culture and fermentation operations is assumed.</td>
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<tr>
<td>06-623</td>
<td>Mathematical Modeling of Chemical Engineering Processes</td>
<td>12</td>
<td>Numerical approaches to solving problems relevant to chemical engineering applications. In this course, advanced mathematical topics relevant to chemical engineering will be used to solve complex problems. Topics include linear algebra, nonlinear equation solving, initial value and boundary value problems for solution of differential equations, numerical optimization, probability and stochastic methods. Significant focus will be placed on numerical rather than analytical solution to problems. Primary Software Package(s): Mathematical programming environment.</td>
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<tr>
<td>06-625</td>
<td>Chemical and Reactive Systems</td>
<td>12</td>
<td>In this course process simulation software will be used to develop models of chemical and reactive systems. The models will be used to predict the performance of the system, as well as to probe how process modifications, e.g. process conditions, reactor types or sequences, etc? affect system performance. The effects of the underlying thermodynamic and kinetic databases of chemical properties on the performance predictions will be explored. Methods to incorporate new thermodynamic and kinetic data into chemical and reactive system simulations will be examined. Thermochemical and kinetic data for reactions will be estimated for use in process simulation software. Primary Software Package(s): Molecular modeling and process simulation software.</td>
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<tr>
<td>06-636</td>
<td>Bioseparations</td>
<td>6</td>
<td>This course will focus on the current and future technologies utilized for the separation and purification of biomacromolecules and cells in the biotechnology and pharmaceutical industries as well as in research and development areas. Specifically, the course will focus on plasmid DNA, adenoviruses and similar viruses, recombinant proteins, antibodies, and stem cells. Batch and continuous processing will both be discussed for separation technique and design.</td>
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<tr>
<td>06-637</td>
<td>Spectroscopy and Characterization</td>
<td>6</td>
<td>In the biotechnology and pharmaceutical space, a thorough understanding of analytical techniques is essential for proper in-line monitoring of production, characterization of new products, as well as sustaining consistent products from living systems. This course will provide an overview of the diverse metrics needed for analysis of biomacromolecules as well as the variety of techniques used to analyze quality of produced materials by comparing cost, speed, accuracy and precision. These techniques include, but are not limited to mass spectrometry, electrophoresis, sequencing, UV-visible-NIR absorption spectroscopy, chemometrics, and glycanalytics. Additional topics will include new techniques in development.</td>
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<tr>
<td>06-640</td>
<td>Principles and Applications of Molecular Simulation</td>
<td>9</td>
<td>This course will introduce modern concepts and methods for simulating physical and thermodynamics properties of materials from atomic-scales, with special emphasis on the gas and liquid states. Strengths and limitations of molecular simulation methods will be discussed. Topics will include basic statistical mechanics, interatomic potentials, Molecular Dynamics methods, Monte Carlo methods, computation of phase coexistence curves, and Brownian Dynamics.</td>
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<tr>
<td>06-663</td>
<td>Analysis and Modeling of Transport Phenomena</td>
<td>12</td>
<td>Students will learn the basic differential equations and boundary conditions governing momentum, heat, and mass transfer. Students will learn how to think about these equations in dimensionless terms and will apply them to model physical and chemical processes. The primary mode for solving them will be numerical. Analytical results for classical problems of high symmetry also will be presented to serve as a basis for comparison and validation. Software: A finite element and computational transport tool.</td>
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<tr>
<td>06-665</td>
<td>Process Systems Modeling</td>
<td>12</td>
<td>Simulation and optimization of complex flowsheets, synthesis of separation systems, planning and enterprise-wide optimization, process control and molecular design. Primary Software Package(s): Process Simulation software. Target Audience: first year masters students in chemical engineering. Prerequisite skills: analytical and mathematical skills typical of an undergraduate engineering degree or technical degree.</td>
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<tr>
<td>06-679</td>
<td>Introduction to Meteorology</td>
<td>12</td>
<td>Provide you with the basics of meteorology, with a focus on large-scale atmospheric motion. By the end of the course, you will have an understanding of the basics of atmospheric dynamics, including horizontal and vertical motion, as well as the vertical structure of the atmosphere (atmospheric stability and boundary-layer dynamics). You will understand what makes weather happen and you will understand weather maps and charts. You will be able to critically watch the nightly weather forecast and you will be able to access available meteorological databases to make informed predictions of your own. Finally, you will understand atmospheric transport and boundary-layer dynamics, which will serve as a foundation for other coursework involving atmospheric transport and air-pollution if you are pursuing those topics more deeply.</td>
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06-681 Special Topics: Data Science and Machine Learning in Chemical Engineering
Fall and Spring: 6 units
This class will examine topics related to data science and machine learning in chemical engineering. This may include topics in data visualization and modeling, differentiable programming, and the use of data and models to design experiments. The course will emphasize computational implementations of these topics using Python, with applications in chemical engineering. Students will need to be comfortable with scientific programming using Python. Students who have taken 06-623 and/or 06-625 should have the skills needed in this class.

06-682 ST: Data Science & Machine Learning in Chemical Engineering: Scientific Software
Fall and Spring: 6 units
Creating scientific research software. This class will introduce topics in software engineering for scientific research. We will cover using a shell for running command line programs, automation tools for building software, version control systems, and how to create and distribute software packages. Prior programming experience with Python is highly recommended. The course will include a final project in developing a software package that is to be used in scientific research.

06-705 Advanced Chemical Engineering Thermodynamics
Fall: 12 units
Advanced application of the general thermodynamic method to chemical engineering problems. Second law consequences, estimation and correlation of thermodynamic properties, and chemical and phase equilibria.

06-714 Surfaces and Adsorption
Fall and Spring: 12 units
A survey of solid surfaces and gas-solid interactions. Topics include the structure and electronic properties of metal surfaces, the kinetics and thermodynamics of adsorption and desorption processes, and concepts in heterogeneous catalysis. The course emphasizes the application of recent experimental techniques in studying these problems.

06-722 Bioprocess Design
Fall and Spring: 12 units
This course is designed to link concepts of cell culture, bioseparations, formulation, and delivery together for the commercial production and use of biologically-based pharmaceuticals; products considered include proteins, nucleic acids, and fermentation-derived fine chemicals. Associated regulatory issues and biotech industry case studies are also included. A fair knowledge of cell culture and fermentation operations is assumed.