CHEMICAL AND BIOMOLECULAR ENGINEERING

http://www.jhu.edu/chembe/

Chemical and Biomolecular Engineering (ChemBE) is dedicated to the design and exploitation of chemical, biological, and to the study of phenomena for chemical and biological applications. As a result of the scope and breadth of this rigorous undergraduate program, our students commonly secure employment in industries such as chemical and pharmaceutical production, biomedicine, biotechnology, material design, food, and energy. Graduates may embark on a career to explore new products such as:

<table>
<thead>
<tr>
<th>Novel polymers and materials</th>
<th>Biopharmaceuticals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuels</td>
<td>Drugs and Vaccines</td>
</tr>
<tr>
<td>Gene Therapy Products</td>
<td>Drug Delivery Devices</td>
</tr>
<tr>
<td>Cells and Tissues</td>
<td>Semiconductors</td>
</tr>
<tr>
<td>Nanodevices</td>
<td>Food, Beverage, and Health Care Products</td>
</tr>
</tbody>
</table>

The demands on the modern engineer are high, and graduates must possess a wide range of skills in order to be competitive in a global market. The ChemBE program successfully satisfies these demands. Students take advanced courses in chemistry, physics, mathematics, and biology. Additionally, students are trained in transport, kinetics, and thermodynamics, which are essential to solving real-world engineering problems. Students also hone their professional and communication skills (report writing, oral presentations, and teamwork) in courses involving experimental projects, process design and product design.

Depending on their interests and future career goals, students can choose electives from exciting areas including green engineering, nanotechnology, and bioengineering. These courses, along with undergraduate research opportunities offered by our faculty, are designed to prepare graduates for careers in the chemical industry, biotechnology, pharmaceuticals or microelectronics. The curriculum also offers an outstanding foundation for advanced graduate studies in chemical, biological, cellular and molecular levels. Common areas utilizing skills in these focus areas include the genetic manipulation of cells for protein and vaccine production, and the study and treatment of diseases such as arteriosclerosis and cancer. Students in this focus area must take a laboratory course in Biochemistry, and two electives such as Metabolic Systems Biotechnology, The Design of Biomolecular Systems, and Computational Protein Structure Prediction. In addition, students will take the Biomolecular Engineering Laboratory to learn the hands-on skills required for future careers in biological systems at the molecular and cellular level.

Our mission is to define and educate a new archetype of innovative and fundamentally-grounded engineer at the undergraduate and graduate levels through the fusion of fundamental chemical engineering principles and emerging disciplines. We will nurture our passion for technological innovation, scientific discovery, and leadership in existing and newly created fields that transcend traditional boundaries. We will be known for developing leaders in our increasingly technological society who are unafraid to explore uncharted engineering, scientific, and medical frontiers that will benefit humanity. Recent graduates of the Chemical and Biomolecular Engineering program will attain within a few years of graduation:

- succeed in careers in industrial, academic or government organizations in which they apply their chemical and biomolecular engineering skills to solve diverse long-standing or emerging problems
- excel in their graduate program, medical school or other professional education
- be recognized as future leaders in their chosen field
- perpetuate the JHU legacy of passion for learning, technical excellence, community service and research innovation to foster knowledge creation, lead discovery and impact society.

The department also offers graduate programs leading to the Master of Science and Ph.D. degrees. These programs emphasize research leading to a written thesis.

Undergraduate students strongly involved in research may be interested in our B.S./M.S.E. program in Chemical and Biomolecular Engineering that allows students to obtain a master’s of science in engineering immediately after completion of their bachelors.

Facilities

The offices and state-of-the-art laboratories of Chemical and Biomolecular Engineering are located in Maryland Hall on the Homewood campus. The research laboratories are well-equipped for studies in the areas of biochemical engineering, cell and tissue engineering, phase equilibria, membrane science, polymer science, interfacial phenomena, separation processes, fluid mechanics, and nucleation phenomena. The Milton S. Eisenhower Library on the Homewood campus contains over two million volumes and access to more than 325 electronic journals. The university’s other libraries located at the School of Medicine and at the Applied Physics Laboratory are also available to students. Through close collaborations with scientists at the National Institutes of Health, and the National Institute of Standards and Technology, The Institute for Genomic Research, Human Genome Sciences, Inc., and the Food and

Molecular and Cellular Bioengineering (MCB) Track

Fields in biotechnology and biomedicine often involve processes at biological, cellular and molecular levels. Common areas utilizing skills in the MCB focus area include the genetic manipulation of cells for protein and vaccine production, and the study and treatment of diseases such as arteriosclerosis and cancer. Students in this focus area must take a laboratory course in Biochemistry, and two electives such as Metabolic Systems Biotechnology, The Design of Biomolecular Systems, and Computational Protein Structure Prediction. In addition, students will take the Biomolecular Engineering Laboratory to learn the hands-on skills required for future careers in biological systems at the molecular and cellular level.

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Interfaces and Nanotechnology (IN) Track

Interesting and new physics exist at nanometer length scales, as the surface area of an object begins to approach and exceed its volume. In this focus area, students are trained in the fundamental sciences used to solve problems in nanotechnology and interfacial science. Students take a chemistry course in Materials and Surface Characterization, an advanced physical chemistry laboratory course, and two electives such as Colloids and Nanoparticles, Supramolecular Materials and Nanomedicine and Micro/Nanotechnology.
Drug Administration, students and faculty also have access to a variety of world-class facilities and other resources for research.

### Financial Aid

Undergraduate scholarships and financial assistance are described on the Student Financial Services (http://finaid.johnshopkins.edu) website. Part-time work is available in the Chemical and Biomolecular Engineering research laboratories on research projects supported by grants and contracts. There also is a federally sponsored work-study program for qualified students.

Financial assistance to graduate students is available in the forms of research assistantships, teaching assistantships, fellowships, and partial or full tuition remission. The financial aid package is specified following acceptance into the graduate program.

Graduates receive a Bachelor of Science degree in Chemical and Biomolecular Engineering accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. As permitted under the ABET guidelines, we are continually updating our undergraduate programs to include the latest advances in chemical and biomolecular engineering. Such modifications will enable us to offer the best possible educational experience to our undergraduates. For the latest chemical engineering educational programs, potential applicants are referred to our website at http://www.jhu.edu/chembe/

### Requirements for the B.S. Degree

(See also General Requirements for Departmental Majors (http://catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree))

The Bachelor of Science degree requires a minimum of 128 credits. Additional details are given in the Chemical and Biomolecular Engineering Undergraduate Advising Manual available from the department or online. The 128 credits must include:

#### Chemical and Biomolecular Engineering Core Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.101</td>
<td>Chemical Engineering Today</td>
<td>1</td>
</tr>
<tr>
<td>EN.540.202</td>
<td>Introduction to Chemical &amp; Biological Process</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Analysis</td>
<td></td>
</tr>
<tr>
<td>EN.540.203</td>
<td>Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.301</td>
<td>Kinetic Processes</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.303</td>
<td>Transport Phenomena I</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.304</td>
<td>Transport Phenomena II</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.305</td>
<td>Modeling and Statistical Analysis of Data for</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Chemical and Biomolecular Engineers</td>
<td></td>
</tr>
<tr>
<td>EN.540.306</td>
<td>Chemical &amp; Biomolecular Separation</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.311</td>
<td>Projects in ChemE Unit Operations with Experiments</td>
<td>6</td>
</tr>
<tr>
<td>or EN.540.313</td>
<td>Projects in ChemBE Unit Operations with Experiments</td>
<td>6</td>
</tr>
<tr>
<td>EN.540.314</td>
<td>ChemBE Product Design</td>
<td>2</td>
</tr>
<tr>
<td>or EN.540.309</td>
<td>Product Design Part 1</td>
<td></td>
</tr>
<tr>
<td>or EN.540.310</td>
<td>Product Design Part 2</td>
<td></td>
</tr>
<tr>
<td>EN.540.315</td>
<td>Process Design with Aspen</td>
<td>2</td>
</tr>
<tr>
<td>EN.540.409</td>
<td>Dynamic Modeling and Control</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.490</td>
<td>Introduction to Chemical Process Safety</td>
<td>1</td>
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#### Engineering Electives

9 credits

#### Physics Courses and Laboratories

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>AS.171.101</td>
<td>General Physics:Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.107</td>
<td>General Physics for Physical Sciences Majors (AL)</td>
<td></td>
</tr>
<tr>
<td>AS.173.111</td>
<td>General Physics Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.171.102</td>
<td>General Physics: Physical Science Major II</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.108</td>
<td>General Physics for Physical Science Majors (AL)</td>
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### Basic Chemistry Courses and Laboratories

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.105</td>
<td>Introductory Chemistry Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.030.102</td>
<td>Introductory Chemistry II</td>
<td>3</td>
</tr>
<tr>
<td>or AS.030.103</td>
<td>Applied Chemical Equilibrium and Reactivity w/lab</td>
<td></td>
</tr>
<tr>
<td>AS.030.106</td>
<td>Introductory Chemistry Laboratory II</td>
<td>1</td>
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</tbody>
</table>

### Advanced Chemistry and Biology Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>AS.020.305</td>
<td>Biochemistry</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.307</td>
<td>Cell Biology for Engineers (Optional; students must take this or EN.540.204)</td>
<td>3</td>
</tr>
<tr>
<td>AS.020.315</td>
<td>Biochemistry Project lab</td>
<td>1</td>
</tr>
<tr>
<td>or AS.030.307</td>
<td>Experiments in Physical Chemistry for Engineers</td>
<td></td>
</tr>
<tr>
<td>or AS.250.253</td>
<td>Protein Engineering and Biochemistry Lab</td>
<td></td>
</tr>
<tr>
<td>EN.540.204</td>
<td>Applied Physical Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>or EN.540.307</td>
<td>Cell Biology for Engineers</td>
<td></td>
</tr>
</tbody>
</table>

### Mathematics Requirement

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.211</td>
<td>Honors Multivariable Calculus</td>
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</tr>
<tr>
<td>AS.110.302</td>
<td>Differential Equations and Applications</td>
<td>4</td>
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</table>

### Humanities and Social Sciences/ Writing Requirements

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.661.315</td>
<td>Culture of the Engineering Profession</td>
<td>3</td>
</tr>
</tbody>
</table>

- **Humanities and Social Sciences Courses.** Eighteen credits designated as Humanities or Social and Behavioral Sciences are required. At least one of these courses must be an advanced course at the 300-level or higher in addition to Culture of Engineering. See the Chemical and Biomolecular Engineering Undergraduate Advising Manual for more details.
- **Writing Courses.** Two writing-intensive courses are required. One of the courses must be EN.661.315 Culture of the Engineering Profession. The courses that are taken to satisfy the university writing requirement must be passed with a grade of C- or better.
- The departmental computing requirement is satisfied by EN.540.305 Modeling and Statistical Analysis of Data for Chemical and Biomolecular Engineers. This course can be substituted with a statistics course paired with a programming course such as EN.500.112 Gateway Computing.
- **Undesignated Electives.** A minimum of 128 credits is required for the degree. Therefore, in addition to all the credits taken to fulfill the requirements mentioned in the various sections above (e.g., chemical engineering core courses, engineering electives, basic science, advanced chemistry electives, mathematics requirement, and Humanities and Social and Behavioral Sciences courses) additional credits (called undesignated credits) are required.
Students also must have a grade point average of at least 2.00 in the chemical and biomolecular engineering core courses to graduate. The core courses for GPA calculation comprise all of the above courses except for EN.540.101 Chemical Engineering Today and EN.540.490 Introduction to Chemical Process Safety.

** Students need additional courses beyond these courses. Requirements include additional courses in Chemistry and Biology. Students who are pursuing tracks in Molecular and Cellular Bioengineering or Interfaces and Nanotechnology have additional and/or alternate requirements.

*** Calculus is so essential to Chemical Engineering that a grade of C- or better in both Calculus I and Calculus II is required.

### Sample Program for Chemical and Biomolecular Engineering Degree

#### Freshman

<table>
<thead>
<tr>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>Freshman</td>
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<td>Spring</td>
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<tr>
<td>AS.030.101</td>
<td>Introductory</td>
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<td>AS.030.105</td>
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<td>1</td>
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<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>AS.110.109</td>
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<td>4</td>
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<tr>
<td>AS.171.101</td>
<td>General Physics: Physics Major I</td>
<td>AS.171.102</td>
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<td>AS.173.111</td>
<td>General Physics Laboratory I</td>
<td>AS.173.112</td>
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<tr>
<td>EN.540.101</td>
<td>Chemical Engineering Today</td>
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#### Sophomore

<table>
<thead>
<tr>
<th>Credits</th>
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<tbody>
<tr>
<td>Sophomore</td>
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<tr>
<td>EN.540.202</td>
<td>Introduction to Chemical Biological Process Analysis</td>
<td>EN.540.203</td>
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<td>AS.110.202</td>
<td>Calculus III I</td>
<td>AS.110.302</td>
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<td>AS.020.305</td>
<td>Biochemistry</td>
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<td>AS.030.205</td>
<td>Introductory Organic Chemistry I</td>
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#### Junior

<table>
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<th>Credits</th>
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<td>EN.540.301</td>
<td>Transport Phenomena II</td>
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<tr>
<td>4</td>
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<td>AS.030.305, AS Biology 315, or AS Biophysics 253</td>
<td>Physical Chemistry Instrumentation Laboratory I</td>
<td>EN.540.306</td>
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<tr>
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<tr>
<td>EN.540.305</td>
<td>Modeling and Statistical Analysis of Data for Chemical and Biomolecular Engineers</td>
<td>EN.661.315</td>
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<td>Engineering Elective</td>
<td>Engineering Elective</td>
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<td>EN.540.490</td>
<td>Introduction to Chemical Process Safety</td>
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#### Senior

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<thead>
<tr>
<th>Credits</th>
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<tbody>
<tr>
<td>Senior</td>
<td>Fall</td>
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<tr>
<td>EN.540.311</td>
<td>Projects in ChemE Unit Operations with Experiments</td>
<td>EN.540.314</td>
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<td>6</td>
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<td>EN.540.409</td>
<td>Dynamic Modeling and Control</td>
<td>EN.540.315</td>
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<td>EN.540.316</td>
<td>Advanced Chem/Bio Elective</td>
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</table>

Total Credits: 127-129

### Tracks

Students pursuing a degree in Chemical and Biomolecular Engineering have the option of concentrating on specific fields including Interfaces and Nanotechnology and Molecular and Cellular Bioengineering. Students completing a track will have this fact designated on their official university checklist. These focus areas have additional and/or alternate requirements, as described.

#### Molecular and Cellular Bioengineering (MCB) Track

Students must fulfill the following requirements:

- Students take either AS.020.306 Cell Biology or EN.540.307 Cell Biology for Engineers.
- The Advanced Chemistry and Biology laboratory requirement is fulfilled with AS.020.315 Biochemistry Project lab or AS.250.253 Protein Engineering and Biochemistry Lab.
Six credits of bioengineering electives are required. See department for a list of approved electives.

Students take EN.540.313 Projects in ChemBE Unit Operations with Experiments instead of EN.540.311 Projects in ChemE Unit Operations with Experiments.

### Sample Program: Molecular and Cellular Bioengineering Track

#### Freshman

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
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<tbody>
<tr>
<td>AS.030.101 Introductory Chemistry I</td>
<td>3</td>
<td>AS.030.102 Introductory Chemistry II</td>
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<tr>
<td>AS.030.105 Introductory Chemistry Laboratory I</td>
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<td>AS.030.106 Introductory Chemistry Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
<td>AS.110.109 Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.101 General Physics: Physical Science Major I</td>
<td>4</td>
<td>AS.171.102 General Physics: Physical Science Major II</td>
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<td>AS.173.111 General Physics Laboratory I</td>
<td>1</td>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.101 Chemical Engineering Today</td>
<td>1</td>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
</tr>
<tr>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Credits:</strong></td>
<td>17</td>
<td><strong>Spring Credits:</strong></td>
<td>15</td>
</tr>
</tbody>
</table>

#### Sophomore

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.202 Introduction to Chemical Biological Process Analysis</td>
<td>4</td>
<td>EN.540.203 Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>AS.110.202 Calculus III</td>
<td>4</td>
<td>EN.540.303 Transport Phenomena I</td>
<td>3</td>
</tr>
<tr>
<td>AS.020.305 Biochemistry</td>
<td>4</td>
<td>EN.110.302 Differential Equations and Applications (H/S Elective)</td>
<td>4</td>
</tr>
<tr>
<td>AS.030.205 Introductory Organic Chemistry I</td>
<td>4</td>
<td>EN.540.307 Cell Biology for Engineers</td>
<td>3</td>
</tr>
<tr>
<td><strong>Undesignated Elective:</strong></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Credits:</strong></td>
<td>16</td>
<td><strong>Spring Credits:</strong></td>
<td>16</td>
</tr>
</tbody>
</table>

#### Junior

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.304 Transport Phenomena II</td>
<td>4</td>
<td>EN.540.301 Kinetic Processes</td>
<td>4</td>
</tr>
<tr>
<td>AS.020.315 Biochemistry or AS Biophysics Project lab</td>
<td>1-3</td>
<td>EN.540.306 Chemical Biomolecular Separation</td>
<td>3</td>
</tr>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
<td>AS.110.109 Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total Credits:</strong></td>
<td>16</td>
<td><strong>Spring Credits:</strong></td>
<td>16</td>
</tr>
</tbody>
</table>

### Interfaces and Nanotechnology (IN) Focus Area

Students must fulfill the following requirements

- Students take EN.540.204 Applied Physical Chemistry.
- The Advanced Chemistry and Biology laboratory requirement is fulfilled with AS.030.305 Physical Chemistry Instrumentation Laboratory I.
- AS.030.452 Materials & Surface is required and satisfied three credits of the advanced chemistry electives.
- Six credits of interfaces and nanotechnology electives are required. See department for a list of approved electives.

### Sample Program: Interfaces and Nanotechnology Track

#### Freshman

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.030.101 Introductory Chemistry I</td>
<td>3</td>
<td>AS.030.102 Introductory Chemistry II</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.105 Introductory Chemistry Laboratory I</td>
<td>1</td>
<td>AS.030.106 Introductory Chemistry Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
<td>AS.110.109 Calculus II</td>
<td>4</td>
</tr>
</tbody>
</table>

### Sample Program: Interdisciplinary Engineering Track

#### Freshman

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.305 Modeling and Statistical Analysis of Data for Chemical and Biomolecular Engineers</td>
<td>3</td>
<td>EN.661.315 Culture of the Engineering Profession</td>
<td>3</td>
</tr>
<tr>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
<td>Engineering Elective</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.490 Introduction to Chemical Process Safety</td>
<td>1</td>
<td>3 Advanced Chem/Bio Elective</td>
<td>3</td>
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<tr>
<td><strong>Total Credits:</strong></td>
<td>15-17</td>
<td><strong>Spring Credits:</strong></td>
<td>16</td>
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</table>

#### Senior

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.313 Projects in ChemBE Unit Operations with Experiments</td>
<td>6</td>
<td>EN.540.314 ChemBE Product Design</td>
<td>2</td>
</tr>
<tr>
<td>EN.540.409 Dynamic Modeling and Control</td>
<td>4</td>
<td>EN.540.315 Process Design with Aspen</td>
<td>2</td>
</tr>
<tr>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
<td>Bioengineering Elective</td>
<td>3</td>
</tr>
<tr>
<td>Bioengineering Elective</td>
<td>3</td>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
</tr>
<tr>
<td><strong>Undesignated Electives:</strong></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Credits:</strong></td>
<td>16</td>
<td><strong>Spring Credits:</strong></td>
<td>17</td>
</tr>
</tbody>
</table>
### B.S./M.S.E. Program in Chemical and Biomolecular Engineering

The B.S./M.S.E. program in Chemical and Biomolecular Engineering allows students to obtain a master of science in engineering immediately after the bachelor of science degree by adding at least a year of study. For students who qualify academically, the Whiting School of Engineering allows a 50 percent waiver after the completion of eight semesters or having received the Bachelor of Science degree.

#### Master of Science in Engineering

Students have two options in pursuing an M.S.E. in Chemical and Biomolecular Engineering: (a) a coursework-only MSE, or (b) an essay-based MSE (which entails obtaining approval to work under the guidance of a ChemBE faculty advisor to create and document original research to be submitted in an essay).

1. **Essay-Based Master of Science in Engineering Checklist**
   - The student must complete six graduate level, i.e. 600 and above, courses approved by the student’s research advisor and the Director of the Master’s Program. The student and research advisor select these courses to design a curriculum appropriate for the student’s research interest and educational goals.
   - These six courses cannot include seminars, independent study, graduate research or special studies. They should be at least 3 credit hours per course. Students are allowed to substitute any combination of 1-2 credit hour courses (not to include seminars, independent study, graduate research, or special studies) for one of their 3 credit hour courses with advisor approval.
   - At least four of the six courses must be in the Chemical and Biomolecular Engineering Department (540.xxx or 545.xxx). Exceptions to this rule must be approved by the Director of the Master’s Program. A course from a department other than ChemBE may be allowed to count as one of the four courses only if the course has significant Chemical and Biomolecular Engineering content, is 3 credit hours (or the student intends to use their one allowable substitution on a set of courses that add to three credit hours), and is consistent with the student’s research interests or educational goals.
   - Of the four ChemBE courses, 3 must be the MSE core courses:

<table>
<thead>
<tr>
<th>Senior</th>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.311</td>
<td>Projects in ChemE Unit Operations with Experiments</td>
<td>6</td>
<td>EN.540.314</td>
<td>ChemBE Product Design</td>
</tr>
<tr>
<td>EN.540.409</td>
<td>Dynamic Modeling and Control</td>
<td>4</td>
<td>EN.540.315</td>
<td>Process Design with Aspen</td>
</tr>
<tr>
<td>AS.030.452</td>
<td>Materials Surface</td>
<td>3</td>
<td>Interfaces/Nanotechnology Elective</td>
<td></td>
</tr>
<tr>
<td>Humanities/Nanotechnology Elective</td>
<td>3</td>
<td>Undesignated Electives</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Humanities Electives</td>
<td>3</td>
<td></td>
<td></td>
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<tr>
<td><strong>Total Credits:</strong></td>
<td><strong>132</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Thermodynamics in Practice (Offered in the Fall)
• Kinetics and Reactor Design (Offered in the Spring)
• Transport and Numerical Tools (Offered in the Spring)

• Students are allowed to count 400-level courses towards their MSE degree if the course is not offered at the 600-level. Courses offered at both the 400- and 600-level must be taken at the 600-level to fulfill MSE course requirements. All ChemBE coursework must be taken at the 600-level.

• The student must also enroll in at least one semester of graduate seminars (540.600/601) throughout his or her tenure.

• Students must have a B average in coursework to complete this degree.

• No D grade in ChemBE courses can be counted toward the requirements. In a given semester the receipt of a single D, F, or 2 C grades result in probation. Once in probation an additional C grade or below will result in termination from the program. A student will remain on academic probation until the courses with the D or F grades have been re-taken for a higher grade or (if no D or F grades were present) the student attains a B average in their coursework.

• Students must remain in good research standing with their research advisor. Failure to do so will result in probation and transfer to the coursework MSE program.

• The student must write an essay based on original research and literature review and present his or her results at an open seminar attended by the faculty and students. The essay must be approved by the departmental graduate committee, which consists of the graduate research advisor and at least one more faculty member from the Department of Chemical and Biomolecular Engineering.

• In a semester where the student is solely pursuing research, the student must maintain full-time registration.

• Completion of Responsible Conduct of Research training. For complete information, see eng.jhu.edu/wse/page/conduct-of-research-training

• Completion of Academic Ethics (EN.500.603)

• Please obtain verification and approval to take courses before registering.

Additional information and requirements can be found in the department Graduate Handbook.

Doctor of Philosophy
The Ph.D. degree is awarded for original research performed under the guidance of a thesis advisor. The formal requirements for this degree are:

1. Completion of six graduate-level courses including the four required core courses
2. Completion of an annual research evaluation each year.
3. Serve as a teaching assistant for at least two required courses.
4. Completion in the first semester of departmental safety requirements (see Handbook for more information).
5. Attend graduate seminars (540.600/601) every semester. Students are expected to enroll and attend department seminars throughout their tenure in the department.
7. Completion of an original research project, documented in a dissertation that is defended by the candidate in a public presentation.

8. Completion of Responsible Conduct of Research training. For complete information, see eng.jhu.edu/wse/page/conduct-of-research-training

9. Completion of Academic Ethics (EN.500.603)

10. Application for Graduation submitted to Registrar's office.


Ph.D. Course Work

Students must successfully complete six graduate-level courses including the four required core courses listed below:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.630</td>
<td>Thermodynamics, Statistical Mechanics, and Kinetics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.652</td>
<td>Advanced Transport Phenomena</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.602</td>
<td>Metabolic Systems Biotechnology</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.615</td>
<td>Interfacial Science with Applications to Nanoscale Systems</td>
<td>3</td>
</tr>
</tbody>
</table>

Ph.D. Students are strongly encouraged to take the four required courses in the first fall semester. However, students who do not have an undergraduate degree in Chemical Engineering or a closely related field may need additional course and should discuss an appropriate course plan with the Director of the Graduate Program at the start of their first semester.

The remaining two engineering or science courses are chosen with the help of the student’s advisor to design a curriculum appropriate for the student’s research interest. These two courses cannot include seminars, independent study, graduate research or special studies.

Each of the six courses must be passed with a letter grade of B- or higher. In addition, the student must maintain an overall grade point average (GPA) of 3.0 or better. If the student’s GPA falls below 3.0, the student must re-take one or more of the courses and earn a higher grade. All grades remain on graduate students transcripts. If a student receives a grade of C+ or lower in a required core course, the student will be allowed to re-take the course once to achieve a grade of B- or higher. Failure to receive a B- or better the second time will be cause for dismissal from the program. Receipt of grades of C+ or lower in two or more required courses will ordinarily be cause for dismissal from the program without the opportunity to re-take those courses.

Ph.D. Thesis Criteria and Graduate Board Oral Exam

Candidates must write a dissertation conforming to university requirements that describes the students work and results in detail. A public defense of the dissertation is required, and will be followed by a closed examination session. Because the closed examination session fulfills the university Graduate Board Oral (GBO) examination requirement, all procedures pertaining to GBOs as established by the University Graduate Board must be followed.

Additional information can be found in the department Graduate Handbook.

For current faculty and contact information go to http://www.jhu.edu/chembe/faculty-staff/

Faculty

Chair
Paulette Clancy
Head

Professors

Michael J. Betenbaugh
Professor: genomics, recombinant DNA biotechnology, biopharmaceuticals, metabolic engineering, insect and mammalian cell culture, glycosylation engineering, and cell death processes.

Michael A. Bevan
Professor and Director of Graduate Studies: colloidal interactions, dynamics, assembly, nanoparticle materials and devices, biomacromolecular interactions

Marc D. Donohue
Professor: phase equilibria, statistical thermodynamics, kinetics of diffusion and phase transitions, adsorption.

Sharon Gerecht
Professor: embryonic and adult stem cells, vascular regeneration, micro/nano fabrication, biomaterials, tissue engineering

David H. Gracias
Professor: micro and nanotechnology, surface science, metamaterials, complex systems, nanoelectronics, nanomedicine, regenerative medicine, drug delivery and microfluidics.

Jeffrey J. Gray
Professor and Director of Graduate Admissions: biomolecular modeling, protein-protein docking, therapeutic antibodies, allostery, protein-surface interactions and design.

Yannis Kevrekidis
Bloomberg Distinguished Professor: algorithms, data, computer-assisted modeling of complex dynamical systems.

Efie Kokkoli
Professor: DNA nanotechnology, targeted drug and gene delivery, biopolymers and responsive hydrogels, and tissue engineering.

Rong Li
Bloomberg Distinguished Professor: cellular dynamics in space, time, and adaptation.

Marc A. Ostermeier
Professor: biomolecular engineering, molecular evolution, protein engineering, combinatorial methods, biosensors, protein therapeutics.

Michael Tsapatis
Bloomberg Distinguished Professor: zeolite synthesis, separations, catalysis

Denis Wirtz
Professor and Vice Provost for Research: cell adhesion and migration, cell mechanics, cytoskeleton, receptor-ligand interactions, cancer, particle tracking, new proteomics tools.
**Associate Professors**

Stavroula Sofou  
Associate Professor: heterogeneous lipid bilayers, drug delivery/nanobiomaterials, targeted chemotherapy, alpha-particle therapy.

Honggang Cui  
Associate Professor: nanoscience and nanotechnology, biomolecular engineering, peptide synthesis and assembly, drug delivery, supramolecular polymers, nanoparticle imaging, diagnosis, and cancer therapeutics.

Joelle Frechette  
Associate Professor and Director of Master’s Studies: properties of surfaces, thin films; fluid interfaces and confined fluids; measurements of surface forces and adhesion; micro and nanotechnology; microfluidics; nanoparticles.

Rebecca Schulman  
Associate Professor: nanotechnology, self-assembly, theory and experiment, nucleation, biotechnology, DNA, nanoelectronics, biomolecular engineering, single-molecular analysis.

**Assistant Professors**

Jamie Spangler  
Assistant Professor: structural and molecular immunology, protein engineering, therapeutic antibody discovery and design, targeted drug development.

Chao Wang  
Assistant Professor: heterogenous catalysis, renewable energy technologies e.g., photoelectrochemical solar cells and lithium batteries, and green chemical engineering.

**Senior Lecturer**

Lise Dahuron  
Senior Lecturer and Director of Undergraduate Studies: separations, distillation, membrane technology, new product development, process design.

Carmo Pereira  
Senior Lecturer: catalysis and reaction engineering in chemical engineering practice.

**Lecturer**

Sakul Ratanalert  
Lecturer: Engineering Education, Unit Operations, Process Design, Thermodynamics, DNA Nanotechnology

**Professor Emeritus**

Joseph L. Katz  
Professor Emeritus: nucleation processes (e.g., condensation of supersaturated vapors, boiling of superheated liquids and its applications, e.g., the Ouzo effect, parts per quad-rillion detection) formation of nanosized ceramic oxide powders in flames, new proteomics tools.

**Research Professor**

Gregory Aranovich  
Research Professor: molecular thermodynamics, phase equilibria, adsorption phenomena, separation processes, and diffusion.

**Assistant Research Professor**

Daniele Gilkes

Eva Lai

Assistant Research Professor: biomedical sciences, biomonitoring technologies, regenerative medicine, tissue engineering.

**Joint, Part-Time and Visiting Appointments**

Steven An  
Associate Professor, Johns Hopkins University Bloomberg School of Public Health

Patrick Breysse  
Professor, Johns Hopkins University School of Medicine, Division of Environmental Health Engineering

Jennifer Elisseeff  
Professor, Johns Hopkins University School of Medicine, Department of Ophthalmology Director of the Translational Tissue Engineering Center

Jonah Erlebacher  
Professor & Chair, Johns Hopkins University Whiting School of Engineering, Materials Science and Engineering

Justin Hanes  
Lewis J. Ort Professor of Ophthalmology, Johns Hopkins University School of Medicine, Ophthalmology

John Isaacs  
Professor, Johns Hopkins University, School of Medicine

Kenneth Pienta  
Professor, Johns Hopkins University School of Medicine, Urology Research

Martin Pomper  
Professor, Johns Hopkins University School of Medicine, Radiology

Kai Qi  
Adjunct Assistant Professor

Kannan Rangaramanujam  
Professor, Johns Hopkins University School of Medicine, Ophthalmology

Doug Robinson  
Professor, Johns Hopkins University School of Medicine, Cell Biology

Peter Searson  
Professor, Johns Hopkins University Whiting School of Engineering, Materials Science and Engineering

Joy Yang  
Visiting Associate Professor

Jin Zhang  
Professor, Johns Hopkins University School of Medicine, Pharmacology

For current course information and registration go to https://sis.jhu.edu/classes/
Courses

EN.540.101. Chemical Engineering Today. 1.0 Credit.
A series of weekly lectures to introduce students to chemical and biomolecular engineering and its role as a profession in addressing contemporary technological, social, ethical, and economic issues in today's world. The lectures will include examples of how chemical and biomolecular engineers apply the principles of physics and chemistry to develop new products, improve process efficiencies, and alleviate the strain on the ecosystem through the design of novel environmentally conscious processes. In addition, the lectures will highlight exciting new areas now being advanced by chemical and biomolecular engineers, such as biochemical engineering, tissue engineering, nanoparticle fabrication, and processing smart polymers for applications in computer technology and as sensors. Freshmen Only.
Instructor(s): X. Wan
Area: Engineering.

EN.540.111. Matlab Made Easy. 1.0 Credit.
Computer programming is as crucial a tool for modern engineering as calculus. Engineers use computers for almost everything: from design and manufacturing in industry to data collection and analysis in research. In this course, students will use a piece of popular engineering software, Matlab, to learn the fundamentals of programming. We will start simple, exploring such questions as: What is a program? How can we use loops and branches to accomplish a task? What exactly is Matlab doing when it's running a script? Finally, we will build upon the fundamentals of programming to tackle relevant engineering problems. This course will help ChemBE students excel in subsequent engineering courses, such as Modeling and Statistics for ChemBEs, Separations, and Chemical Kinetics, by giving students' knowledge of the tool that helps solve complex engineering problems.
Instructor(s): E. Volkova; H. Zierden; S. Schaffter
Area: Engineering.

EN.540.202. Introduction to Chemical & Biological Process Analysis. 4.0 Credits.
Introduction to chemical and biomolecular engineering and the fundamental principles of chemical process analysis. Formulation and solution of material and energy balances on chemical processes. Reductionist approaches to the solution of complex, multi-unit processes will be emphasized. Introduction to the basic concepts of thermodynamics as well as chemical and biochemical reactions.
Prerequisites: (AS.030.101 OR AS.030.103) AND (AS.171.101 OR AS.171.107) AND (AS.030.102 OR AS.030.103 OR AS.110.109 OR AS.171.102)
Instructor(s): J. Gray
Area: Engineering.

EN.540.203. Engineering Thermodynamics. 3.0 Credits.
Formulation and solution of material, energy, and entropy balances with an emphasis on open systems. A systematic problem-solving approach is developed for chemical and biomolecular process-related systems. Extensive use is made of classical thermodynamic relationships and constitutive equations for one and two component systems. Applications include the analysis and design of engines, refrigerators, heat pumps, compressors, and turbines.
Prerequisites: EN.540.202, AS.110.202
Instructor(s): J. Frechette; M. Bevan
Area: Engineering.

EN.540.204. Applied Physical Chemistry. 3.0 Credits.
The topics in this course include thermodynamic models for multicomponent phase equilibrium including vaporliquid equilibrium, phase diagrams, activity models and colligative properties in both non-electrolyte and electrolyte solutions. A link between average thermodynamic properties and microstates and molecular interactions is made via a discussion of intermolecular forces and the partition function. Also covered are thermodynamic relationships to describe chemical equilibria, and basic concepts in quantum mechanics and statistical mechanics.
Prerequisites: EN.540.203 AND EN.540.305
Instructor(s): D. Gracias
Area: Engineering.

EN.540.290. Chemical Engineering Modeling and Design for Sophomores. 3.0 Credits.
The courses EN.540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfill a societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.
Instructor(s): M. Donohue
Area: Engineering.

EN.540.291. Chemical Engineering Modeling and Design for Sophomores. 3.0 Credits.
The courses EN.540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfill a societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.
Instructor(s): M. Donohue
Area: Engineering.

EN.540.301. Kinetic Processes. 4.0 Credits.
Review of numerical methods applied to kinetic phenomena and reactor design in chemical and biological processes. Homogeneous kinetics and interpretation of reaction rate data. Batch, plug flow, and stirred tank reactor analyses, including reactors in parallel and in series. Selectivity and optimization considerations in multiple reaction systems. Non isothermal reactors. Elements of heterogeneous kinetics, including adsorption isotherms and heterogeneous catalysis. Coupled transport and chemical/biological reaction rates.
Prerequisites: EN.540.203 AND EN.540.303; EN.540.305 or programming course
Instructor(s): H. Cui
Area: Engineering.
EN.540.303. Transport Phenomena I. 3.0 Credits.
Molecular mechanisms of momentum transport (viscous flow), energy transport (heat conduction), and mass transport (diffusion). Isothermal equations of change (continuity, motion, and energy). The development of the Navier Stokes equation. The development of non isothermal and multi component equations of change for heat and mass transfer. Exact solutions to steady state, isothermal unidirectional flow problems, to steady state heat and mass transfer problems. The analogies between heat, mass, and momentum transfer are emphasized throughout the course.
Prerequisites: AS.110.302
Instructor(s): J. Frechette
Area: Engineering.

EN.540.304. Transport Phenomena II. 4.0 Credits.
Prerequisites: EN.540.303.
Instructor(s): Z. Gagnon
Area: Engineering.

EN.540.305. Modeling and Statistical Analysis of Data for Chemical and Biomolecular Engineers. 3.0 Credits.
This course seeks to build the student’s strength in Chemical Engineering computing and data analysis. To this end, in the first part of the course, we will become familiar with the Matlab/Octave computing environment and solve problems in Chemical Engineering that involve concepts from Process Analysis, Thermodynamics, Transport Phenomena, and Kinetics. In the subsequent part, we will build on the skills learnt earlier and tackle problems in Data Analysis and Hypothesis testing.
Prerequisites: EN.540.302 AND AS.110.302
Instructor(s): R. Schulman
Area: Engineering.

EN.540.306. Chemical & Biomolecular Separation. 3.0 Credits.
This course covers staged and continuous-contacting separations processes critical to the chemical and biochemical industries. Separations technologies studied include distillation, liquid-liquid extraction, gas absorption, membrane ultrafiltration, reverse osmosis, dialysis, adsorption, and chromatography. Particular emphasis is placed on the biochemical uses of these processes and consequently on how the treatment of these processes differs from the more traditional approach.
Prerequisites: EN.540.203 AND EN.540.305 or programming course.
Instructor(s): M. Betenbaugh
Area: Engineering.

EN.540.307. Cell Biology for Engineers. 3.0 Credits.
This course explores fundamental structural details and molecular functions of different parts of the cell. Considerable emphasis is placed on experimental/quantitative approaches to answering these questions. Topics include Central dogma and the nucleus; protein trafficking; ion transporters; cytoskeleton; molecular motors; cell cycle and cell division; signal transduction, cell growth and cancer; cell death, the extracellular matrix; cell adhesion, cell junctions and epithelium; and muscle contraction, cell motility and morphogenesis.
Prerequisites: Cell Biology restriction: students who have completed AS.020.306 may not enroll.
Instructor(s): J. Yang, R. Li
Area: Natural Sciences.

EN.540.309. Product Design Part 1. 2.0 Credits.
This course guides the student through the steps of product design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill the needs. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the primary objectives of the course. Students report several times both orally and in writing on their accomplishments. This course is the first part of a two-semester sequence that optionally can be taken instead of EN.540.314 Chemical and Biomolecular Engineering Product Design. The material covered is the same as in EN.540.314, but more time is allowed so that laboratory tests can be performed and/or prototypes can be made. Note that students must take 540.310 to complete this sequence and before receiving credits for 540.309.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.;EN.540.303 AND EN.540.490;EN.540.306 AND EN.540.301
Instructor(s): M. Donohue
Area: Engineering.

EN.540.310. Product Design Part 2. 2.0 Credits.
This course is one part of a two semester sequence that optionally can be taken instead of for This course is the second part of a two semester sequence (with EN.540.309) that optionally can be taken instead of EN.540.314 Chemical and Biomolecular Engineering Product Design. Students continue to work with their team on their product design project. Students report several times both orally and in writing on their accomplishments. The material covered is the same as in EN.540.314, but more time is allowed so that laboratory tests can be performed and/or prototypes can be made. Note that both courses, EN.540.309 and EN.540.310 must be taken to satisfy the Undergraduate degree requirement of the Chemical and Biomolecular Engineering program. The two courses can be started in any term.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.;EN.540.309
Instructor(s): M. Donohue
Area: Engineering.
EN.540.311. Projects in ChemE Unit Operations with Experiments. 6.0 Credits.
This course challenges students with laboratory projects that are not well-defined. Students work in groups to develop an effective approach to experiments. They identify the important operating variables, decide how best to obtain them using measured or calculated values. Based on their results they predict, carryout, analyze and improve experiments. Each student analyzes three of the following projects: distillation, gas absorption, and one of the projects in EN.540.313. In addition to technical objectives, this course stresses oral and written communication. Students will have additional meeting times with the instructors and some writing professors outside of class.   
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.;EN.540.301 AND EN.540.304 AND EN.540.306 AND EN.540.490 AND EN.661.315  
Instructor(s): A. Goffin; L. Dahuron; M. Ostermeier; S. Gerecht  
Area: Engineering  
Writing Intensive

EN.540.312. Projects in ChemBE Unit Operations with Experiments Part 2. 3.0 Credits.  
Students who, as a part of an exchange program, participated in a laboratory course at the Technical University of Denmark at Copenhagen during the summer are required to register for this course to complete their equivalency requirement for the Chemical and Biomolecular Engineering Laboratory course offered in fall at JHU. The final grade for this course will incorporate the DTU grade. In addition, students perform one experimental project and submit a full professional report along with the current Senior Lab students. Students make a 15-min presentation to the junior class about their projects and of their experience in Denmark.  
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.;EN.540.301 AND EN.540.304 AND EN.540.306 AND EN.540.490 AND EN.661.315  
Instructor(s): C. Pereira; L. Dahuron  
Area: Engineering  
Writing Intensive

EN.540.313. Projects in ChemBE Unit Operations with Experiments. 6.0 Credits.  
This course challenges students with laboratory projects that are not well-defined. Students work in groups to develop an effective approach to experiments. They identify the important operating variables, decide how best to obtain them using measured or calculated values. Based on their results they predict, carryout, analyze and improve experiments. Each student analyzes at least two of the following biomolecular projects: bioreactor, biocatalysis and membrane separation and one of the projects in EN.540.311. In addition to technical objectives, this course stresses oral and written communication. Students will have additional meeting times with the instructors and some writing professors outside of class.  
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.;EN.540.301 AND EN.540.304 AND EN.540.306 AND EN.540.490 AND EN.661.315  
Instructor(s): A. Goffin; L. Dahuron; M. Ostermeier; S. Gerecht  
Area: Engineering  
Writing Intensive

EN.540.314. ChemBE Product Design. 2.0 Credits.  
This course guides the student through the contrasting aspects of product design and of process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill the needs. Process design concerns the quantitative description of processes, which serve to produce many commodity chemicals, the estimation of process profitability, and the potential for profitability improvement through incremental changes in the process. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the primary objectives of the course. Students report several times both orally and in writing on their accomplishments.  
Prerequisites: EN.540.303;EN.540.306 AND EN.540.301  
Instructor(s): A. Goffin; C. Pereira; T. Fekete  
Area: Engineering

EN.540.315. Process Design with Aspen. 2.0 Credits.  
Prerequisites: EN.540.303;EN.540.306 AND EN.540.301  
Instructor(s): A. Goffin; L. Dahuron  
Area: Engineering

EN.540.390. Chemical Engineering Modeling and Design for Juniors. 3.0 Credits.  
The courses EN.540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfill a societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.  
Instructor(s): M. Donohue  
Area: Engineering

EN.540.391. Chemical Engineering Modeling and Design for Juniors. 3.0 Credits.  
The courses EN.540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfill a societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.  
Instructor(s): M. Donohue  
Area: Engineering
EN.540.400. Project in Design: Pharmacokinetics. 3.0 Credits.
This is a design course in which the design projects will be to use chemical process simulation tools to model a real-world, alternative-energy process of interest to Chemical and Biomolecular Engineers. The goal of the project will be to develop a process model that is sufficiently complete and robust that it can be used to understand the important factors in the process design and/or operation. This design project is focused on the role alternative energy will play in our country’s future. About a third of the course will be devoted to a technical and economic analysis of the alternative energy technology. This course is organized to replicate group project work as it is practiced in industry. The class is divided into groups (typically 3 or 4 students) and each group will meet separately each week with the instructor. Hence, there is no regularly scheduled class times; student groups sign up for weekly meeting times using Starfish in Blackboard. These meetings typically will be 90 minutes long. The expectations and assignments for this course are quite different from most other courses. There are no weekly lectures by the instructor. Rather, each week each group will make a PowerPoint presentation on the week’s topic or their progress on their project.
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.401. Projects in Design: Alternative Energy. 3.0 Credits.
This course is a group design project (i.e. not a lecture course) to develop pharmacokinetic models of the human body that can be used to understand the temporal distribution, spatial distribution and bioavailability of pharmaceutical drugs. The course (and software to be developed) will cover the spectrum of factors affecting pharmaceutical bioavailability including drug formulation, mode of dosing and dosing rate, metabolism and metabolic cascades, storage in fatty tissues, and diffusional limitations (such as in crossing the blood-brain barrier or diffusional differences between normal and cancerous cells). The goal is to develop process models of the human body that will predict pharmaceutical bioavailability as a function of time and organ (or cell) type that will work for a wide variety of pharmaceuticals including small molecules, biologics, and chemotherapy agents. This course is organized to replicate group project work as it is practiced in industry. The class is divided into groups (typically 3 or 4 students) and each group will meet separately each week with the instructor. Hence, there is no regularly scheduled class times; student groups sign up for weekly meeting times using Starfish in Blackboard. These meetings typically will be 90 minutes long. The expectations and assignments for this course are quite different from most other courses. There are no weekly lectures by the instructor. Rather, each week each group will make a PowerPoint presentation on the week’s topic or their progress on their project.
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.402. Metabolic Systems Biotechnology. 3.0 Credits.
The aim of this course is to provide a fundamental understanding of the quantitative principles and methodologies of systems biology and biochemical engineering of metabolism. This includes concepts of cellular growth, cellular stoichiometric models, metabolic networks, metabolite fluxes, and genome-scale metabolic models. Quantitative methods and systems biology approaches for metabolic flux analysis and metabolic control theory will be included as well as an analysis of biochemical systems and bioreactors including a consideration of mass transport processes.
Prerequisites: AS.020.306 OR (EN.580.440 OR EN.580.441) OR EN.540.307
Instructor(s): M. Betenbaugh
Area: Engineering.

EN.540.403. Colloids and Nanoparticles. 3.0 Credits.
Fundamental principles related to interactions, dynamics, and structure in colloidal, nanoparticle, and interfacial systems. Concepts covered include hydrodynamics, Brownian motion, diffusion, sedimentation, electrophoresis, colloidal and surface forces, polymeric forces, aggregation, deposition, and experimental methods. Modern topics related to colloids in nano-science and technology will be discussed throughout the course with frequent references to recent literature. Meets with EN.540.603
Instructor(s): M. Bevan
Area: Engineering.

EN.540.404. The Design of Biomolecular Systems. 3.0 Credits.
This course covers new topics in the design of systems of biomolecules, both in vitro and in vivo, for decision making and control. The course will begin with an overview of how logical decision making and control with biomolecules as is achieved in biology and then proceed to consider various strategies of engineering similar systems. The focus of the course will be on systems level principles rather than the biochemistry of molecule design. Topics will include engineering of transcriptional networks and genetic control for logically programming of cells, the design of in vitro mimics of genetic controls, molecular computing and systems aspects of metabolic engineering. The course will also cover quantitative and computational techniques for the simulation and analysis of biomolecular systems. Co-listed with EN.540.605
Instructor(s): R. Schulman
Area: Engineering.

EN.540.405. Dynamic Modeling and Control. 4.0 Credits.
Introduction to modeling, dynamics, and control. Unsteady state analysis of biophysical transport processes. Applications of chemical engineering (chemical reactors and separative processes) as well as biomolecular engineering (biosynthesis, pharmacokinetic modeling and biomolecular modeling based upon central dogma/gene expression). Introduction to nonlinear dynamics.
Prerequisites: EN.540.301 AND EN.540.306
Instructor(s): A. Goffin
Area: Engineering, Quantitative and Mathematical Sciences.
EN.540.414. Computational Protein Structure Prediction and Design. 3.0 Credits.
This class will introduce the fundamental concepts in protein structure, biophysics, optimization and informatics that have enabled the breakthroughs in computational structure prediction and design. Problems covered will include protein folding and docking, design of ligand-binding sites, design of turns and folds, design of protein interfaces. Class will consist of lectures and hands-on computer workshops. Students will learn to use molecular visualization tools and write programs with the PyRosetta protein structure software suite, including a computational project. Programming experience is recommended.
Instructor(s): J. Gray
Area: Engineering.

EN.540.415. Interfacial Science with Applications to Nanoscale Systems. 3.0 Credits.
Nanostructured materials intrinsically possess large surface area (interface area) to volume ratios. It is this large interfacial area that gives rise to many of the amazing properties and technologies associated with nanotechnology. In this class we will examine how the properties of surfaces, interfaces, and nanoscale features differ from their macroscopic behavior. We will compare and contrast fluid-fluid interfaces with solid-fluid and solid-solid interfaces, discussing fundamental interfacial physics and chemistry, as well as touching on state-of-the-art technologies.
Instructor(s): J. Frechette
Area: Engineering.

EN.540.418. Projects in the Design of a Chemical Car. 2.0 Credits.
Ready to put those concepts from class into practice? Members work over the course of the semester to design and build a chemically powered vehicle that will compete with other college teams at the American Institute of Chemical Engineers (AIChE) Regional Conference. In this course, the students work in small groups to design and construct the chassis along with chemically powered propulsion and break mechanisms within the constraints of the competition. In addition, students will give oral presentation, write reports, and do thorough safety analysis of their prototypes. Both semesters (EN.540.418 and EN.540.419) must be completed with passing grades to receive credit. This course may be repeated.
Instructor(s): L. Dahuron
Area: Engineering.

EN.540.419. Projects in the Design of a Chemical Car. 2.0 Credits.
Ready to put those concepts from class into practice? Members work over the course of the semester to design and build a chemically powered vehicle that will compete with other college teams at the American Institute of Chemical Engineers (AIChE) Regional Conference. In this course, the students work in small groups to design and construct the chassis along with chemically powered propulsion and break mechanisms within the constraints of the competition. In addition, students will give oral presentation, write reports, and do thorough safety analysis of their prototypes. Both semesters (EN.540.418 and EN.540.419) must be completed with passing grades to receive credit.
Instructor(s): L. Dahuron
Area: Engineering.

EN.540.421. Project in Design: Pharmacodynamics. 3.0 Credits.
This is continuation of 540.400 Project in Design: Pharmacokinetics. It is a design course in which the design projects will be to develop pharmacodynamic models of the human body that can be used to understand the physiologic effects of drugs on the body. The course (and software to be developed) will cover the spectrum of ways in which pharmaceuticals affect human physiology. The goal is to develop process models of the human body that will predict pharmaceutical effects as a function of time and organ (or cell) type that will work for a wide variety of pharmaceuticals including small molecules, biologics, and chemotherapy agents. This course is organized to replicate group project work as it is practiced in industry. The class is divided into groups (typically 3 or 4 students) and each group will meet separately each week with the instructor. Hence, there is no regularly scheduled class times; student groups sign up for weekly meeting times using Starfish in Blackboard. These meetings typically will be 90 minutes long. The expectations and assignments for this course are quite different from most other courses. There are no weekly lectures by the instructor. Rather, each week each group will make a PowerPoint presentation on the week’s topic or their progress on their project. Prerequisites 540.421 has a prerequisite of 540.400 Pharmacokinetics
Prerequisites: EN.540.400
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.422. Introduction to Polymeric Materials. 3.0 Credits.
Polymeric materials are ubiquitous in our society from Nature-made proteins and polysaccharides to synthetic plastics and fibers. Their applications range from day-to-day consumables to high performance materials used in critically demanding areas, such as aviation, aerospace and medical devices. The objective of this course is to provide an introductory overview on the field of polymer science and engineering. Students will learn some basic concepts in polymer synthesis, characterization, and processing. With the basic concepts established, industrial applications of polymeric materials will be discussed in two categories: structural polymers and functional polymers. Structural polymers, including plastics, fibers, rubbers, coatings, adhesives, and composites, will be discussed in terms of their structure, processing, and property relationship with a flavor of industrial relevant products and applications. Future trends in developing environmentally friendly polymers from renewable resources (“green polymer chemistry”) will also be covered. Lectures on functional polymers will be focused on their unique properties that are enabled by rational molecular design, controlled synthesis and processing (e.g. supramolecular assembly, and microfabrication). This class of specialty materials can find their use in high performance photovoltaics, batteries, membranes, and composites, and can also serve as “smart” materials for use in coatings, sensors, medical devices, and biomimicry.
Instructor(s): H. Cui; K. Qi
Area: Engineering.
EN.540.428. Supramolecular Materials and Nanomedicine. 3.0 Credits.
Nanomedicine is a quickly growing area that exploits the novel chemical, physical, and biological properties of nanostructures and nanostructured materials for medical treatments. This course presents basic design principles of constructing nanomaterials for use in drug delivery, disease diagnosis and imaging, and tissue engineering. Three major topics will be discussed, including 1) nanocarriers for drug delivery that are formed through soft matter assembly (e.g., surfactants, lipids, block copolymers, DNA, polyelectrolytes, peptides), 2) inorganic nanostuctures for disease diagnosis and imaging (e.g., nanoparticles of gold and silver, quantum dots and carbon nanotubes), and 3) supramolecular scaffolds for tissue engineering and regenerative medicine. Students are expected to learn the physical, chemical and biological properties of each nanomaterial, the underlying physics and chemistry of fabricating such material, as well as their advantages and potential issues when used for biomedical applications. This course will also provide students opportunities for case studies on commercialized nanomedicine products. After this class, students should gain a deeper understanding of current challenges in translating nanoscience and nanotechnology.
Instructor(s): H. Cui
Area: Engineering.

EN.540.436. Design: Pharmacokinetics/Dynamics. 3.0 Credits.
This is a one semester overview of year long course; students that want a comprehensive understanding of pharmacokinetics and pharmacodynamics should take the 2 courses EN.540.400 and EN.540.421. This course covers the principles of pharmacokinetics and pharmacodynamics. Computer models of pharmacokinetic and pharmacodynamics behavior will be developed and then used to design better drug delivery regimens and to analyze drug chemistry modifications. The course (and software to be developed) will cover the spectrum of factors affecting pharmaceutical effects on physiology including drug formulation, mode of dosing and dosing rate, metabolism and metabolic cascades, storage in fatty tissues, and diffusional limitations (such as in crossing the blood-brain barrier or diffusional differences between normal and cancerous tissues). This course is organized to replicate group project work as it is practiced in industry. The class is divided into groups (typically 3 or 4 students) and each group will meet separately each week with the instructor. Hence, there is no regularly scheduled class times; student groups sign up for weekly meeting times using Starfish in Blackboard. These meetings typically will be 90 minutes long. The expectations and assignments for this course are quite different from most other courses. There are no weekly lectures by the instructor. Rather, each week each group will make a PowerPoint presentation on the week’s topic or their progress on their project. Prerequisites 540.436 has a prerequisite of 540.301 Kinetic Processes
Prerequisites: EN.540.301
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.437. Application of Molecular Evolution to Biotechnology. 3.0 Credits.
One of the most promising strategies for successfully designing complex biomolecular functions is to exploit nature’s principles of evolution. This course provides an overview of the basics of molecular evolution as well as its experimental implementation. Current research problems in evolution-based biomolecular engineering will be used to illustrate principles in the design of biomolecules (i.e. protein engineering, RNA/ DNA engineering), genetic circuits and complex biological systems including cells. Meets with EN.540.537
Prerequisites: AS.020.305 OR EN.580.221 OR permission of instructor.
Instructor(s): M. Ostermeier
Area: Engineering, Natural Sciences.

EN.540.438. Advanced Topics in Pharmacokinetics and Pharmacodynamics I. 3.0 Credits.
This course involves a semester-long project in pharmacodynamics. Topics are chosen in consultation with instructor.
Prerequisites: EN.540.400 AND (EN.540.421 OR EN.540.436)
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.439. Advanced Topics in Pharmacokinetics and Pharmacodynamics II. 3.0 Credits.
This course involves a semester-long project in pharmacodynamics. Topics are chosen in consultation with instructor.
Prerequisites: EN.540.421 OR EN.540.436
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.440. Micro/Nanotechnology: The Science and Engineering of Small Structures. 3.0 Credits.
The field of micro / nanotechnology has been gaining tremendous momentum as evidenced by an explosive rise in the number of publications, patents and commercial activities. This is an introductory course intended to expose students to the field as well as real world applications. Lectures will include an overview of scaling of material properties at the nanoscale, micro and nanofabrication methods and essential analytical tools of relevance to the field. All through the course, we will go over electronic, optical and biological applications of emerging micro and nanoscale devices and materials. Co-listed with EN.540.640.
Instructor(s): D. Gracias
Area: Engineering.

EN.540.452. Eukaryotic Cell Biotechnology. 2.0 Credits.
This course involves integrated lecture/discussion and laboratory components to review and participate in current and emerging topics involving eukaryotic biotechnology. Lectures and discussions review how fundamentals of biochemical kinetics and biomolecular engineering are connected to emerging problems in mammalian, algal, and stem cell biotechnology. Laboratory activities are connected to diverse scientific and technological fundamental topics on these same themes. Journal article and research presentations provide a context for laboratory activities with respect to emerging industrial applications for eukaryotic cell types. Research design and strategy is discussed in terms of its ultimate implementation in laboratory, pilot plant, and eventually manufacturing facilities. Methodologies implemented include cell and metabolic engineering for improving yields and production rates of proteins, cells, and tissues. Example topics include expansion of mammalian, stem cells, and algae for the production of membrane proteins, biologics, biofuels, and complex metabolites. Consent of instructor only.
Instructor(s): M. Betenbaugh
Area: Engineering.
EN.540.455. Current Topics in DNA Nanotechnology Practicum. 3.0 Credits.
Research laboratory elective course where students can learn DNA nanotechnology and build nanostructures.
Instructor(s): R. Schulman.

EN.540.460. Polymer Physics. 3.0 Credits.
This course will cover the physics aspect of macromolecular/polymeric materials. We will discuss the molecular origin of key physical phenomena, such as chain relaxation, time temperature superposition, free volume, high strain rate behavior, phase transitions, flow and fracture as well as physical aging. Many real world examples will be used throughout the course. We will also discuss the recent advances in biopolymers, polymers for 3D printing, electro-spinning and polymers for tissue engineering. Students should have introductory training in Materials Science.
Prerequisites: AS.030.101 AND AS.171.101
Instructor(s): Z. Xia
Area: Engineering, Natural Sciences.

EN.540.462. Polymer Design and Bioconjugation. 3.0 Credits.
This course will focus on conventional to most recent inventions on polymer and conjugation chemistry. The weekly lectures will include the reaction strategy, designs and characterization techniques, structure-property relationship, simplistic approaches and versatile application oriented-solutions to Biomaterials and Tissue engineering related challenges. Students will learn how to devise creative strategies, process design and product development. Preliminary knowledge of organic chemistry is expected.
Instructor(s): A. Singh
Area: Engineering, Natural Sciences.

EN.540.465. Engineering Principles of Drug Delivery. 3.0 Credits.
Fundamental concepts in drug delivery from an engineering perspective. Biological organisms are viewed as highly interconnected networks where the surfaces/interfaces can be activated or altered ‘chemically’ and ‘physically/mechanically’. The importance of intermolecular and interfacial interactions on drug delivery carriers is the focal point of this course. Topics include: drug delivery mechanisms (passive, targeted); therapeutic modalities and mechanisms of action; engineering principles of controlled release and quantitative understanding of drug transport (diffusion, convection); effects of electrostatics, macromolecular conformation, and molecular dynamics on interfacial interactions; thermodynamic principles of self-assembly; chemical and physical characteristics of delivery molecules and assemblies (polymer based, lipid based); significance of biodistributions and pharmacokinetic models; toxicity issues and immune responses.
Prerequisites: Students may take EN.540.465 or EN.540.665, but not both.
Instructor(s): S. Sofou
Area: Engineering, Natural Sciences.

EN.540.468. Introduction to Nonlinear Dynamics and Chaos. 3.0 Credits.
An introduction to the phenomenology of nonlinear dynamic behavior with emphasis on models of actual physical, chemical, and biological systems, involving an interdisciplinary approach to ideas from mathematics, computing, and modeling. The common features of the development of chaotic behavior in both mathematical models and experimental studies are stressed, and the use of modern data-mining tools to analyze dynamic data will be explored. Knowledge of Linear Algebra and Ordinary Differential Equations is a prerequisite (at an undergraduate level); Some computing experience is desirable. Emphasis will be placed on the geometric/visual computer-aided description and understanding of dynamics and chaos.
Prerequisites: Students may receive credit for only one of EN.553.473 OR EN.553.673 OR EN.540.468 OR EN.540.668.;((AS.110.201 OR AS.110.212) AND (AS.110.302 OR AS.110.306)) OR EN.553.291
Instructor(s): Y. Kevrekidis
Area: Engineering, Quantitative and Mathematical Sciences.

EN.540.490. Introduction to Chemical Process Safety. 1.0 Credit.
An elementary introduction to chemical process safety, this course covers a selection of topics in chemical process safety analysis and management, taken against the backdrop of real processes and process accidents. Topics include materials compatibility, risk assessment, reactive chemical hazard, process hazard analysis via the HAZOP method, fire/explosion and toxic release incidents, incident investigation, inerting with nitrogen, and Inherently Safer Design.
Prerequisites: EN.540.203 AND EN.540.303
Instructor(s): D. Kuespert
Area: Engineering.

EN.540.501. Independent Research. 3.0 Credits.
Instructor(s): Staff.

EN.540.502. Independent Study. 0.0 - 3.0 Credits.
Instructor(s): J. Frechette; K. Konstantopoulos; M. Donohue; M. Ostermeier; S. Gerecht.

EN.540.503. Independent Research. 0.0 - 3.0 Credits.
Instructor(s): Staff.

EN.540.509. Undergraduate Internship. 1.0 Credit.
Internship unpaid and approved by ChemBE faculty.

EN.540.511. Group Undergraduate Research. 1.0 - 3.0 Credits.
Students do individual projects (or in collaboration with faculty and/or graduate students) in areas basic to chemical engineering. This section has weekly research group meeting that students are expected to attend.
Instructor(s): Staff.

EN.540.513. Group Undergraduate Research. 1.0 - 3.0 Credits.
Students do individual projects (or in collaboration with faculty and/or graduate students) in areas basic to chemical engineering. This section has weekly research group meeting that students are expected to attend.
Instructor(s): Staff.

EN.540.522. Independent Research. 0.0 - 3.0 Credits.
Instructor(s): Staff.

EN.540.596. Summer Internship.
Summer internship paid and approved by ChemBE faculty.
Instructor(s): Staff.

EN.540.597. Research. 3.0 Credits.
Instructor(s): Staff.

EN.540.598. Summer Internship. 1.0 Credit.
Summer internship unpaid and approved by ChemBE faculty.
Instructor(s): D. Wirtz; G. Drazer; H. Cui.
EN.540.599. Independent Study - Summer. 0.0 - 3.0 Credits.
Instructor(s): Staff.

EN.540.600. Chemical and Biomolecular Engineering Seminar. 1.0 Credit.
Lectures are presented on current subjects relevant to chemical engineering. Attendance at 80% of departmental seminars is required to receive credit for this class.
Instructor(s): C. Wang; S. Sofou
Area: Engineering.

EN.540.601. Chemical and Biomolecular Engineering Seminar. 1.0 Credit.
Instructor(s): C. Wang; S. Sofou
Area: Engineering.

EN.540.602. Metabolic Systems Biotechnology. 3.0 Credits.
The aim of this course is to provide a fundamental understanding of the quantitative principles and methodologies of systems biology and biochemical engineering of metabolism. This includes concepts of cellular growth, cellular stoichiometric models, metabolic networks, metabolite fluxes, and genome-scale metabolic models. Quantitative methods and systems biology approaches for metabolic flux analysis and metabolic control theory will be included as well as an analysis of biochemical systems and bioreactors including a consideration of mass transport processes.
Instructor(s): M. Betenbaugh
Area: Engineering.

EN.540.603. Colloids and Nanoparticles. 3.0 Credits.
Fundamental principles related to interactions, dynamics, and structure in colloidal, nanoparticle, and interfacial systems. Concepts covered include hydrodynamics, Brownian motion, diffusion, sedimentation, electrophoresis, colloidal and surface forces, polymeric forces, aggregation, deposition, and experimental methods. Modern topics related to colloids in nano-science and technology will be discussed throughout the course with frequent references to recent literature.
Meets with EN.540.403
Instructor(s): M. Bevan
Area: Engineering.

EN.540.604. Transport Phenomena in Practice. 3.0 Credits.
Required course for ChemBE Masters students
Instructor(s): L. Santhanam
Area: Engineering, Quantitative and Mathematical Sciences.

EN.540.605. The Design of Biomolecular Systems. 3.0 Credits.
This course covers new topics in the design of systems of biomolecules, both in vitro and in vivo, for decision making and control. The course will begin with an overview of how logical decision making and control with biomolecules as is achieved in biology and then proceed to consider various strategies of engineering similar systems. The focus of the course will be on systems level principles rather than the biochemistry of molecule design. Topics will include engineering of transcriptional networks and genetic control for logically programming of cells, the design of in vitro mimics of genetic controls, molecular computing and systems aspects of metabolic engineering. The course will also cover quantitative and computational techniques for the simulation and analysis of biomolecular systems. Co-listed with EN.540.405
Instructor(s): R. Schulman
Area: Engineering.

EN.540.606. Chemical & Biomolecular Separation. 3.0 Credits.
This course covers staged and continuous-contacting separations processes critical to the chemical and biochemical industries. Separations technologies studied include distillation, liquid-liquid extraction, gas absorption, membrane ultrafiltration, reverse osmosis, dialysis, adsorption, and chromatography. Particular emphasis is placed on the biochemical uses of these processes and consequently on how the treatment of these processes differs from the more traditional approach. Only with permission of the instructor. Co-listed with EN.540.306
Instructor(s): M. Betenbaugh.

EN.540.610. Chemical and Biomolecular Engineering Design: Spring. 3.0 Credits.
This course is one part of a two semester sequence. This course guides the student through the contrasting aspects of product design and of process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill the needs. Process design concerns the quantitative description of processes which serve to produce many commodity chemicals, the estimation of process profitability, and the potential for profitability improvement through incremental changes in the process. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the primary objectives of the course. Students report several times both orally and in writing on their accomplishments. Laboratory tests can be performed and/or prototypes can be made. Note that both courses, 540.609 and 540.610 must be taken, the two courses can be started in any term.
Instructor(s): M. Donohue
Area: Engineering.

EN.540.614. Computational Protein Structure Prediction and Design. 3.0 Credits.
This class will introduce the fundamental concepts in protein structure, biophysics, optimization and informatics that have enabled the breakthroughs in computational structure prediction and design. Problems covered will include protein folding and docking, design of ligand-binding sites, design of turns and folds, design of protein interfaces. Class will consist of lectures and hands-on computer workshops. Students will learn to use molecular visualization tools and write programs with the PyRosetta protein structure software suite, including a computational project. Programming experience is recommended.
Instructor(s): J. Gray
Area: Engineering.

EN.540.615. Interfacial Science with Applications to Nanoscale Systems. 3.0 Credits.
Nanostructured materials intrinsically possess large surface area (interface area) to volume ratios. It is this large interfacial area that gives rise to many of the amazing properties and technologies associated with nanotechnology. In this class we will examine how the properties of surfaces, interfaces, and nanoscale features differ from their macroscopic behavior. We will compare and contrast fluid-fluid interfaces with solid-fluid and solid-solid interfaces, discussing fundamental interfacial physics and chemistry, as well as touching on state-of-the-art technologies.
Instructor(s): J. Frechette
Area: Engineering.
EN.540.619. Projects in Design: Alternative Energy. 3.0 Credits.
This course is a group design project (i.e. not a lecture course) to use chemical process simulation tools to model a real-world, alternative-energy process of interest to Chemical and Biomolecular Engineers. The goal of the project will be to develop a process model that is sufficiently complete and robust that it can be used to understand the important factors in the process design and/or operation. This design project is focused on the role alternative energy will play in our country’s future. About a third of the course will be devoted to understanding the role of energy and alternative energy in the US and world economies. The remainder of the course will be devoted to a technical and economic analysis of an alternative energy technology. This course is organized to replicate group project work as it is practiced in industry. The class is divided into groups (typically 3 or 4 students) and each group will meet separately each week with the instructor. Hence, there is no regularly scheduled class times; student groups sign up for weekly meeting times using Starfish in Blackboard. These meetings typically will be 60 minutes long. The expectations and assignments for this course are quite different from most other courses. There are no weekly lectures by the instructor. Rather, each week each group will make a PowerPoint presentation on the week’s topic or their progress on their project. Graduate level. Meets with EN.540.401
Prerequisites: EN.540.202 AND EN.540.203 AND EN.540.301 AND EN.540.305
Instructor(s): M. Donohue
Area: Engineering.

EN.540.621. Project in Design: Pharmacodynamics. 3.0 Credits.
This course covers pharmacodynamics, i.e. how pharmaceuticals affect biological processes. The course will use MatLab to aid in the design of new drug formulations.
Prerequisites: EN.540.632
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.622. Introduction to Polymeric Materials. 3.0 Credits.
Polymeric materials are ubiquitous in our society from Nature-made proteins and polysaccharides to synthetic plastics and fibers. Their applications range from day-to-day consumables to high performance materials used in critically demanding areas, such as aviation, aerospace and medical devices. The objective of this course is to provide an introductory overview on the field of polymer science and engineering. Students will learn some basic concepts in polymer synthesis, characterization, and processing. With the basic concepts established, industrial applications of polymeric materials will be discussed in two categories: structural polymers and functional polymers. Structural polymers, including plastics, fibers, rubbers, coatings, adhesives, and composites, will be discussed in terms of their structure, processing, and property relationship with a flavor of industrial relevant products and applications. Future trends in developing environmentally friendly polymers from renewable resources (“green polymer chemistry”) will also be covered. Lectures on functional polymers will be focused on their unique properties that are enabled by rational molecular design, controlled synthesis and processing (e.g. supramolecular assembly, and microfabrication). This class of specialty materials can find their use in high performance photovoltaics, batteries, membranes, and composites, and can also serve as “smart” materials for use in coatings, sensors, medical devices, and biomimicry.
Instructor(s): H. Cui; K. Qi
Area: Engineering.

EN.540.628. Supramolecular Materials and Nanomedicine. 3.0 Credits.
Nanomedicine is a quickly growing area that exploits the novel chemical, physical, and biological properties of nanostructures and nanostructured materials for medical treatments. This course presents basic design principles of constructing nanomaterials for use in drug delivery, disease diagnosis and imaging, and tissue engineering. Three major topics will be discussed, including 1) nanocarriers for drug delivery that are formed through soft matter assembly (e.g., surfactants, lipids, block copolymers, DNA, polyelectrolytes, peptides), 2) inorganic nanostructures for disease diagnosis and imaging (e.g., nanoparticles of gold and silver, quantum dots and carbon nanotubes), and 3) supramolecular scaffolds for tissue engineering and regenerative medicine. Students are expected to learn the physical, chemical and biological properties of each nanomaterial, the underlying physics and chemistry of fabricating such material, as well as their advantages and potential issues when used for biomedical applications. This course will also provide students opportunities for case studies on commercialized nanomedicine products. After this class, students should gain a deeper understanding of current challenges in translating nanoscience and nanotechnology into medical therapies.
Instructor(s): H. Cui
Area: Engineering, Natural Sciences.

EN.540.630. Thermodynamics, Statistical Mechanics, and Kinetics. 3.0 Credits.
In this course we will aim for understanding the thermodynamics of chemical and bio-molecular systems. We will first review classical, macroscopic thermodynamics covering concepts such as equilibrium, stability and the role of thermodynamic potentials. Our goal will be to gain a feel for the generality of thermodynamics. Statistical mechanics provides a link between the mechanics of atoms and macroscopic thermodynamics. We will introduce this branch in two distinct ways: 1) following standard methods of developing concepts such as ensembles and partition functions, and 2) where we will treat the basis of statistical mechanics as a problem in inference. With this foundation, we will consider concepts relevant to understanding the liquid state. Chemical transformations in a liquid are of importance in much of chemistry and biology, quasi-chemical generalizations of the potential distribution theorem will be introduced to present these ideas. We hope to give an overview of modern developments relating equilibrium work to non-equilibrium work, as these are of increasing importance in studies on single molecule systems. Registration by instructor permission only.
Instructor(s): C. Wang
Area: Engineering.
EN.540.632. Project in Design: Pharmacokinetics. 3.0 Credits.
This is a design course in which the design projects will be to
develop pharmacokinetic models of the human body that can be
used to understand the temporal distribution, spatial distribution and
bioavailability of pharmaceutical drugs. The course (and software to be
developed) will cover the spectrum of factors affecting pharmaceutical
bioavailability including drug formulation, mode of dosing and dosing
rate, metabolism and metabolic cascades, storage in fatty tissues, and
diffusional limitations (such as in crossing the blood-brain barrier or
diffusional differences between normal and cancerous cells). The
goal is to develop process models of the human body that will predict
pharmacological bioavailability as a function of time and organ (or cell)
type that will work for a wide variety of pharmaceuticals including small
molecules, biologics, and chemotherapy agents. This course is organized
to replicate group project work as it is practiced in industry. The class is
divided into groups (typically 3 or 4 students) and each group will meet
separately each week with the instructor. Hence, there is no regularly
scheduled class times; student groups sign up for weekly meeting
times using Starfish in Blackboard. These meetings typically will be 90
minutes long. The expectations and assignments for this course are
quite different from most other courses. There are no weekly lectures
by the instructor. Rather, each week each group will make a PowerPoint
presentation on the week’s topic or their progress on their project.
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.636. Design: Pharmacokinetics/Dynamics. 3.0 Credits.
One semester overview of year long course, students that want
a comprehensive understanding of pharmacokinetics and pharmacodynamics should take the 2 all 540.632 Projects in Design: Pharmacokinetics Spring 540.621 Projects in Design: Pharmacodynamics. This course covers the principles of pharmacokinetics and pharmacodynamics. Computer models of pharmacokinetic and pharmacodynamic behavior will be developed and then used to design better drug delivery regimens and to analyze drug chemistry modifications.
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.637. Application of Molecular Evolution to Biotechnology. 3.0 Credits.
One of the most promising strategies for successfully designing complex
biomolecular functions is to exploit nature’s principles of evolution.
This course provides an overview of the basics of molecular evolution as well as its experimental implementation. Current research problems in evolution-based biomolecular engineering will be used to illustrate principles in the design of biomolecules (i.e. protein engineering, RNA/DNA engineering), genetic circuits and complex biological systems including cells. A course in Biochemistry or Molecular Biology is recommended Meets with EN.540.437
Instructor(s): M. Ostermeier
Area: Engineering, Natural Sciences.

EN.540.638. Advanced Topics in Pharmacokinetics and Pharmacodynamics I. 3.0 Credits.
This course involves a semester-long project in pharmacodynamics.
Topics are chosen in consultation with instructor.
Prerequisites: EN.540.400 AND EN.540.421 OR EN.540.436
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.639. Advanced Topics in Pharmacokinetics and Pharmacodynamics I. 3.0 Credits.
This course involves a semester-long project in pharmacodynamics.
Topics are chosen in consultation with instructor.
Prerequisites: EN.540.400 AND EN.540.421 OR EN.540.436
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.640. Micro/Nanotechnology: The Science and Engineering of Small Structures. 3.0 Credits.
The field of micro / nanotechnology has been gaining tremendous
momentum as evidenced by an explosive rise in the number of
publications, patents and commercial activities. This is an introductory
course intended to expose students to the field as well as real world
applications. Lectures will include an overview of scaling of material
properties at the nanoscale, micro and nanofabrication methods and
essential analytical tools of relevance to the field. All through the course,
we will go over electronic, optical and biological applications of emerging
micro and nanoscale devices and materials. Co-listed with EN.540.440.
Instructor(s): D. Gracias.

EN.540.652. Advanced Transport Phenomena. 3.0 Credits.
It is the goal of this course to move the graduate student (and advanced
undergraduate student) from the introductory level of transport
phenomena (undergraduate) to a level that will allow them to be effective
in researching transport-related topics in a variety of biomedical,
chemical and biochemical engineering areas. The basic equations that
govern mass, momentum, and energy transport will be derived and used
to solve problems that demonstrate the physical insight necessary to
apply these equations to original situations. Some topics include solution
techniques utilizing expansions of harmonic functions, singularity
solutions, lubrication theory for flow in confined geometries, boundary
layer theory, Stokes flow, forced convection, buoyancy-driven flow, Taylor-
Aris dispersion, and reaction-diffusion.
Instructor(s): Z. Gagnon
Area: Engineering.

EN.540.660. Polymer Physics. 3.0 Credits.
This course will cover the physics aspect of macromolecular/polymeric
materials. We will discuss the molecular origin of key physical
phenomena, such as chain relaxation, time temperature superposition,
free volume, high strain rate behavior, phase transitions, flow and
fracture as well as physical aging. Many real world examples will be
used throughout the course. We will also discuss the recent advances
in biopolymers, polymers for 3D printing, electro-spinning and polymers
for tissue engineering. Students should have introductory training in
Materials Science.
Instructor(s): Z. Xia
Area: Engineering, Natural Sciences.

EN.540.661. Nanobioengineering Laboratory. 3.0 Credits.
Students explore different experimental methodologies in
Nanobioengineering. Students work in small teams to complete one or
more major projects expanding their understanding and applying their
theoretical knowledge to practical problems. The course will employ
a variety of experimental methods, from material synthesis to biological
applications. Students report several times either orally and in writing
on their accomplishments. Project meetings may be held outside of the
appointed class time. Graduate students only
Instructor(s): A. Goffin; X. Wan.
EN.540.662. Polymer Design and Bioconjugation. 3.0 Credits.
This course will focus on conventional to most recent inventions on polymer and conjugation chemistry. The weekly lectures will include the reaction strategy, designs and characterization techniques, structure-property relationship, simplistic approaches and versatile application oriented-solutions to Biomaterials and Tissue engineering related challenges. Students will learn how to devise creative strategies, process design and product development.
Instructor(s): A. Singh
Area: Engineering, Natural Sciences.

EN.540.663. Thermodynamic Independent Study. 3.0 Credits.
In this course, we will discuss the important role that thermodynamics plays in chemical engineering practice. After a short review of the first and second laws, we will examine how thermodynamic concepts affect mass and energy balances. We will discuss the properties of systems containing pure species and mixtures and how to analyze the behavior of ideal and real systems. We will estimate heat effects associated with temperature change, phase change, and chemical reaction. The theory associated with properties of pure fluids will be discussed along its application to flow processes. We will present the framework for understanding solution thermodynamics and mixing. Applications of thermodynamics especially important to chemical engineers, such as vapor-liquid equilibrium in distillation and chemical reaction equilibrium in kinetics and reaction engineering, will be discussed. Examples will serve to illustrate how thermodynamic calculations are an integral part of the design and optimization of chemical processes.
Instructor(s): C. Pereira
Area: Engineering.

EN.540.665. Engineering Principles of Drug Delivery. 3.0 Credits.
Fundamental concepts in drug delivery from an engineering perspective. Biological organisms are viewed as highly interconnected networks where the surfaces/interfaces can be activated or altered 'chemically' and 'physically/mechanically'. The importance of intermolecular and interfacial interactions on drug delivery carriers is the focal point of this course. Topics include: drug delivery mechanisms (passive, targeted); therapeutic modalities and mechanisms of action; engineering principles of controlled release and quantitative understanding of drug transport (diffusion, convection); effects of electrostatics, macromolecular conformation, and molecular dynamics on interfacial interactions; thermodynamic principles of self-assembly; chemical and physical characteristics of delivery molecules and assemblies (polymer based, lipid based); significance of biodistributions and pharmacokinetic models; toxicity issues and immune responses.
Prerequisites: Students may take EN.540.465 or EN.540.665, but not both.
Instructor(s): S. Sofou
Area: Engineering, Natural Sciences.

EN.540.668. Introduction to Nonlinear Dynamics and Chaos. 3.0 Credits.
This course will focus on conventional to most recent inventions on polymer and conjugation chemistry. The weekly lectures will include the reaction strategy, designs and characterization techniques, structure-property relationship, simplistic approaches and versatile application oriented-solutions to Biomaterials and Tissue engineering related challenges. Students will learn how to devise creative strategies, process design and product development.
Instructor(s): A. Singh
Area: Engineering, Natural Sciences.

EN.540.669. Introduction to Nonlinear Dynamics and Chaos. 3.0 Credits.
An introduction to the phenomenology of nonlinear dynamic behavior with emphasis on models of actual physical, chemical, and biological systems, involving an interdisciplinary approach to ideas from mathematics, computing, and modeling. The common features of the development of chaotic behavior in both mathematical models and experimental studies are stressed, and the use of modern data-mining tools to analyze dynamic data will be explored. Knowledge of Linear Algebra and Ordinary Differential Equations is a prerequisite (at an undergraduate level); Some computing experience is desirable. Emphasis will be placed on the geometric/visual computer-aided description and understanding of dynamics and chaos.
Prerequisites: Students may receive credit for only one of EN.553.473 OR EN.553.673 OR EN.540.468 OR EN.540.668.;((AS.110.201 OR AS.110.212) AND ( S.110.302 OR AS.110.306) OR EN.553.291[C]
Instructor(s): Y. Kevrekidis
Area: Engineering, Quantitative and Mathematical Sciences.

EN.540.671. Advanced Thermodynamics in Practice. 3.0 Credits.
In this course, we will discuss the important role that thermodynamics plays in chemical engineering practice. After a short review of the first and second laws, we will examine how thermodynamic concepts affect mass and energy balances. We will discuss the properties of systems containing pure species and mixtures and how to analyze the behavior of ideal and real systems. We will estimate heat effects associated with temperature change, phase change, and chemical reaction. The theory associated with properties of pure fluids will be discussed along its application to flow processes. We will present the framework for understanding solution thermodynamics and mixing. Applications of thermodynamics especially important to chemical engineers, such as vapor-liquid equilibrium in distillation and chemical reaction equilibrium in kinetics and reaction engineering, will be discussed. Examples will serve to illustrate how thermodynamic calculations are an integral part of the design and optimization of chemical processes.
Instructor(s): C. Pereira
Area: Engineering.

EN.540.672. Advanced Chemical Reaction Engineering in Practice. 3.0 Credits.
Chemical reaction engineering deals with the analysis on data and the design of equipment in which reactions occur. Reactors may contain one or more phases and be used to conduct chemical or biochemical transformations. The course will cover the fundamental aspects of kinetics, data acquisition, data interpretation, heterogeneous catalysis and heat and mass transfer for each type of reactor. Special emphasis will be placed on the practical application of reaction engineering in the petrochemical, chemical, biochemical and materials industries. The course will make student aware of the needs and opportunities for chemical reaction engineering in industry.
Instructor(s): C. Pereira
Area: Engineering, Quantitative and Mathematical Sciences.

EN.540.673. Advanced Chemical Reaction Engineering in Practice. 3.0 Credits.
This course will focus on conventional to most recent inventions on polymer and conjugation chemistry. The weekly lectures will include the reaction strategy, designs and characterization techniques, structure-property relationship, simplistic approaches and versatile application oriented-solutions to Biomaterials and Tissue engineering related challenges. Students will learn how to devise creative strategies, process design and product development.
Instructor(s): A. Singh
Area: Engineering, Natural Sciences.

EN.540.674. Special topics in Chemical and Biomolecular Engineering: Interfaces and Nanotechnology. 3.0 Credits.
In this course, students will explore a range of advanced topics in Chemical and Biomolecular engineering. Interfacial phenomena, nanotechnology, physical chemistry, catalysis, transport phenomena and the interplay between these topics will be studied.
Instructor(s): Staff.
EN.540.675. Special topics in Chemical and Biomolecular Engineering: Molecular and Cellular Bioengineering. 3.0 Credits.
Student will study a variety of topics in molecular and cellular bioengineering. Cellular Biology, protein engineering, drug delivery, tissue engineering and polymer design are a selection of subjects that will be addressed in this course.
Instructor(s): Staff.

EN.540.690. Chemical and Biomolecular Engineering Design. 3.0 Credits.
This course is one part of a two semester sequence in Chemical and Biomolecular Engineering Product Design. It is intended for students in the ChemBE master’s program. This course guides the student through the complex process of new product design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill needs. Students work in small teams to develop a new product idea, design the product and then iterate on prototype development. Students report several times both orally and in writing on their accomplishments. Time is allowed so that laboratory tests can be performed and/or prototypes can be built. Note that generally both courses, 540.609 and 540.610 must be taken to complete the prototype development. The two courses can be started in any term.
Instructor(s): M. Donohue
Area: Engineering.

EN.540.801. Graduate Research. 3.0 - 20.0 Credits.
Instructor(s): Staff.

EN.540.803. Independent Research. 3.0 - 20.0 Credits.
Instructor(s): Staff.

Cross Listed Courses
Chemistry
Principles and methods for the design and optimization of new biological systems, from a molecular perspective. Topics include: introduction to genetic parts and modern methods for their assembly; synthesis and incorporation of nucleic acids at the level of nucleotides, genes, and genomes; design of genetic programs; library generation and screening; directed evolution and its application to create new proteins and metabolic pathways; computational design of protein and RNA?using physical and bioinformatic approaches; non-canonical amino acids and genetic code expansion. This course will also feature critical evaluation of the primary literature in this fast-paced field, and practical experience with relevant software and computational tools.
Instructor(s): S. Fried.

Biomedical Engineering
EN.580.646. Molecular Immunoengineering. 3.0 Credits.
An in-depth study of the use of biomolecular engineering tools and techniques to manipulate immune function for clinical translation. The course will begin with a brief overview of the immune system, placing a particular emphasis on the molecular-level interactions that determine phenotypic outcomes. The remainder of the curriculum will address ways in which integrative approaches incorporating biochemistry, structural biophysics, molecular biology, and engineering have been used either to stimulate the immune response for applications in cancer and infectious disease, or to repress immune activation for autoimmune disease therapy. Recommended background: Biochemistry and Cell Biology or the BME Molecules and Cells. Those without recommended background should contact the instructor prior to enrolling.
Instructor(s): J. Spangler
Area: Engineering, Natural Sciences.