The School of Engineering

Dean
Lawrence E. Larson

The mission of Brown University's School of Engineering is to educate future leaders in the fundamentals of engineering in an environment of world-class research. We stress an interdisciplinary approach and a broad understanding of underlying global issues. Collaborations across the campus and beyond strengthen our development of technological advances that address challenges of vital importance to us all.

Along with our associations with the other scholarly disciplines – biology, medicine, physics, chemistry, computer science, the humanities and the social sciences – our co-operations bring unique solutions to challenging problems. The School focuses on unique and innovative clustering of faculty; in terms of research groups, engineers of all types team together with non-engineers to tackle some of the biggest problems facing engineering and science today. Our talents and expertise lie in the interdisciplinary domain where the seemingly diverse disciplines converge.

The School of Engineering offers courses and programs leading to the Bachelor of Science (Sc.B.), the Bachelor of Arts (A.B.), the Master of Science (Sc.M.), the Master of Science in Innovation Management and Entrepreneurship (Sc.M.I.M.E.), and the Doctor of Philosophy (Ph.D.). For additional information please visit the School's website at: http://brown.edu/academics/engineering

Engineering Concentration Requirements

The concentration in Engineering equips students with a solid foundation for careers in engineering, to advance the knowledge base for future technologies, and to merge teaching, scholarship, and practice in the pursuit of solutions to human needs. The concentration offers one standard Bachelor of Arts (A.B.) program and nine Bachelor of Science (Sc.B.) degree program tracks. Of these, seven Sc.B. programs in biomedical, chemical and biochemical, civil through May 2016, computer, electrical, materials, and mechanical engineering are accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/. Sc.B. degree programs in environmental engineering and engineering physics are also offered, but they are not accredited by ABET.

(Note: The civil track has been discontinued for all students entering after fall 2012. Students interested in structural engineering entering in after fall 2012. Students interested in structural engineering entering in the class of 2017 and beyond may pursue a Structures track within the Mechanical Engineering program.). Other programs leading to the Sc.B. or A.B. degrees in Engineering may be designed in consultation with a faculty advisor. These programs must meet the general requirements for concentration programs in the School of Engineering. Students interested in an individualized program should consult with an Engineering faculty member willing to serve as an advisor and obtain the approval of the Engineering Concentration Committee. Engineering students with a particular interest in using their technical skills for the public benefit might also consider the Engaged Scholars Program (https://www.brown.edu/academics/engineering/undergraduate-study/engaged-scholars-program).

Please note that all student concentration forms must be approved by the Engineering Concentration Committee, which reviews them for compliance with all relevant program and accreditation requirements.

Mathematics

Mathematics 0190, 0200 is the preferred sequence of courses to be taken in the freshman year. Students with weak preparation in calculus may start in MATH 0100 and take MATH 0200 in second semester. Students without one year of secondary school level preparation in calculus should take MATH 0090, MATH 0100 in their first year, and should begin their sequence of engineering courses with ENGN 0030 in sophomore year. The courses APMA 0330 & APMA 0340 (Methods of Applied Math I, II) can be taken in the sophomore year as well.

Advanced Placement

Students who have taken Advanced Placement courses in high school and/or have shown proficiency through advanced placement examinations are often able to start at a higher level than suggested by the standard programs below. However, please note that Advanced Placement credit cannot be used to satisfy any concentration requirements. For example, our Sc.B. programs specify that students must take 4 semesters of math while enrolled here at Brown, beginning with MATH 0190 or MATH 0170. If a student comes in with advanced placement credit (e.g. placing out of MATH 0190 or MATH 0200), he/she is strongly recommended to take a higher level math course as a replacement. Examples of such courses are MATH 0520 (Linear Algebra), MATH 1260 (Complex Analysis), MATH 1610 (Probability), MATH 1620 (Statistics), APMA 1170 (Numerical Analysis), APMA 1210 (Operations Research), or APMA 1650 (Statistical Inference). However, the student with advanced placement credit for MATH 0190 or MATH 0200 also has the option of replacing the math course with an advanced-level science course, subject to the approval of the concentration advisor.

Transfer Credit

Students who have successfully completed college courses elsewhere may apply to the University for transfer credit. (See the "Study Elsewhere" section of the University Bulletin for procedures, or contact the Dean of the College.) Transfer courses that are used to meet Engineering concentration requirements must be approved by the student’s concentration advisor, and must be described briefly on the student’s electronic concentration form. Transfer courses that are approved by the concentration advisor to be substantially equivalent to a required Brown course automatically fulfill concentration requirements. In rare cases, students may petition the concentration committee to use courses that do not have an equivalent offered at Brown to meet a concentration requirement. Substitutions of this nature can only be approved if the student’s overall program meets published educational outcomes for the concentration and has sufficient basic science, mathematics, and engineering topics courses to meet relevant accreditation requirements. Students should consult their concentration advisor for assistance with drafting a petition. The decision whether to award concentration credit is made by majority vote of the Engineering Concentration Committee.

Substitutions for Required Courses

In exceptional circumstances, a student may petition the concentration committee to substitute a course in place of a requirement. Such substitutions can only be approved if the student's modified program continues to meet the published educational outcomes for the concentration, and has sufficient basic science, mathematics, and engineering topics courses to meet relevant accreditation requirements. Students wishing to make substitutions of this nature should consult their concentration advisor for assistance with drafting their petition. Approval of the petition is subject to majority vote of the Engineering Concentration Committee.

Standard Program for the A.B. degree:

Candidates for the Bachelor of Arts (A.B.) degree with a concentration in Engineering must complete at least eight approved Engineering courses. The eight courses must include at least two 1000-level Engineering courses. Of these 1000-level courses, one must be a design course and the other an in-classroom experience. Engineering courses. Of these 1000-level courses, one must be a design course and the other an in-classroom experience. The set of Engineering courses must be chosen with careful attention to the prerequisites of the 1000-level courses. Please note that this A.B. degree program is not accredited by ABET.

Not all engineering courses may be used to satisfy the engineering course requirement for the A.B. degree. For example, the following courses cannot be used to satisfy the engineering course requirement for the A.B. degree: ENGN 0020, ENGN 0090, ENGN 0900, ENGN 0930A, ENGN 0930C, ENGN 1010. Therefore, the program of study must be developed through consultation with the concentration advisor.

Brown University
The A.B. program also requires preparation in Mathematics equivalent to MATH 0200 and APMA 0330, as well as at least one college-level science course from the general areas of chemistry, life sciences, physics, or geological sciences. Remedial courses, such as CHEM 0100, cannot be used to satisfy this requirement. A programming course is also recommended, but not required. The entire program is subject to approval by an Engineering Concentration Advisor and the Chair of the Engineering Concentration Committee.

Standard programs for the Sc.B. degree

All Bachelor of Science (Sc.B.) program tracks build upon a common core of engineering knowledge and skills applicable across all engineering disciplines. The goal of this engineering core curriculum is to prepare students to practice engineering in an age of rapidly changing technology. Two-thirds of this four-year program consists of a core of basic mathematics, physical sciences, and engineering sciences common to all branches of engineering, including a thorough grounding in programming and technical problem solving. This core provides our graduates with the basis of theory, design, and analysis that will enable them to adapt to whatever may come along during their careers.

At the same time, the core courses assist students in making informed choices in determining their areas of specialization, at the end of their sophomore year. To this end, first-year students are given an introduction to engineering - featuring case studies from different disciplines in engineering as well as guest speakers from industry. This aspect of the program is different from that at many other schools where students are expected to select a specific branch of engineering much earlier in their academic program.

In addition, all Sc.B. programs in Engineering must be complemented by at least four courses in humanities and social sciences. The minimum four-course humanities and social sciences requirement for the Sc.B. in Engineering cannot be met by advanced placement credit.

Chemical and Biochemical Engineering Track:

The Chemical and Biochemical Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The education objectives of the Chemical and Biochemical Engineering program are to prepare graduates: (1) to pursue productive scientific and technical careers, beginning with entry-level engineering positions in industry, or graduate study in chemical or biochemical engineering or related fields; or to successfully pursue other careers that benefit from the analytical or quantitative skills acquired through the Brown CBE Program; (2) to effectively apply the principles of chemical and biochemical engineering, problem-solving skills, and critical and independent thinking, to a broad range of complex, multidisciplinary technological and societal problems; (3) to communicate effectively, both orally and in writing, to professionals and audiences of diverse backgrounds, and to pursue technical approaches and innovations that address the needs of society in an ethical, safe, sustainable, and environmentally responsible manner. The student outcomes of this program are the ABET (a) - (k) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

1. Core Courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0030</td>
<td>Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0040</td>
<td>Dynamics and Vibrations</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0410</td>
<td>Materials Science</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0510</td>
<td>Electricity and Magnetism</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0720</td>
<td>Thermodynamics</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0810</td>
<td>Fluid Mechanics</td>
<td>1</td>
</tr>
<tr>
<td>BIOL 0200</td>
<td>The Foundation of Living Systems</td>
<td>1</td>
</tr>
<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Advanced Placement Calculus (Physics/ Engineering)</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0170</td>
<td>Advanced Placement Calculus</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Intermediate Calculus (Physics/Engineering)</td>
<td>1</td>
</tr>
</tbody>
</table>

or MATH 0180 | Intermediate Calculus               | 1       |
| MATH 0350   | Honors Calculus                     | 1       |
| APMA 0330   | Methods of Applied Mathematics I, II | 1       |
| or APMA 0350| Applied Ordinary Differential Equations | 1 |
| APMA 0340   | Methods of Applied Mathematics I, II | 1       |
| or APMA 0360| Methods of Applied Mathematics I, II | 1       |

2. Upper-Level Chemical & Biochemical Engineering Curriculum

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>ENGN 1110</td>
<td>Transport and Biotransport Processes</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1120</td>
<td>Chemical and Biochemical Reactor Design</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1130</td>
<td>Phase and Chemical Equilibria</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1710</td>
<td>Heat and Mass Transfer</td>
<td>1</td>
</tr>
<tr>
<td>CHEM 0350</td>
<td>Organic Chemistry</td>
<td>1</td>
</tr>
<tr>
<td>CHEM 0360</td>
<td>Organic Chemistry</td>
<td>1</td>
</tr>
<tr>
<td>or CHEM 0400</td>
<td>Biophysical and Bioinorganic Chemistry</td>
<td>1</td>
</tr>
<tr>
<td>or CHEM 0500</td>
<td>Inorganic Chemistry</td>
<td>1</td>
</tr>
<tr>
<td>or CHEM 1140</td>
<td>Physical Chemistry: Quantum Chemistry</td>
<td>1</td>
</tr>
</tbody>
</table>

Advanced Natural Sciences elective course 1

3. Capstone Design Course

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1140</td>
<td>Chemical Process Design</td>
<td>1</td>
</tr>
</tbody>
</table>

*In addition to program requirements above, students must take four courses in the humanities and social sciences.

Total Credits: 21

1 Note: ENGN 1120 and 1130 are only offered in alternate years.
2 An advanced chemistry course approved by concentration advisor; the following courses are pre-approved for this requirement.
3 An advanced course in the natural sciences approved by the concentration advisor. For suggestions of acceptable courses that fulfill this requirement, please see the concentration advisor.

Civil Engineering Track (Available to students entering Brown on or before the Fall of 2012):

Important Announcement: Civil Engineering program will continue through May 2016, and will be available to all students currently enrolled at Brown, including those who arrived as Freshmen in the Fall of 2012 (the class of 2016). Students entering in the class of 2017 and later, with interest in Structural Engineering will be able to concentrate in this discipline through a Structures track within the Mechanical Engineering program. Students interested in Environmental Problems and Planning are directed to the programs in Chemical and Biochemical Engineering or Environmental Engineering.

The Civil Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The education objectives of the Civil Engineering program are to prepare graduates: (1) to have distinctive careers, beginning with either entry level positions in structural and environmental areas of civil engineering or graduate study in these fields; (2) to adapt to changing opportunities, both in engineering and in other professional and business pursuits; (3) to be ethically responsible, to engage in lifelong learning, and to be of service to the engineering community and to society at large. The student outcomes of this program are the ABET (a) - (k) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

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<td>ENGN 0040</td>
<td>Dynamics and Vibrations</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0310</td>
<td>Mechanics of Solids and Structures</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0410</td>
<td>Materials Science</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0510</td>
<td>Electricity and Magnetism</td>
<td>1</td>
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<td>ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
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<td>ENGN 0720</td>
<td>Thermodynamics</td>
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<tr>
<td>ENGN 0810</td>
<td>Fluid Mechanics</td>
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<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
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<td>Advanced Placement Calculus (Physics/ Engineering)</td>
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</tr>
<tr>
<td>MATH 0170</td>
<td>Advanced Placement Calculus</td>
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| MATH 0350   | Honors Calculus                     | 1       |
| APMA 0330   | Methods of Applied Mathematics I, II | 1       |
| or APMA 0350| Applied Ordinary Differential Equations | 1 |
| APMA 0340   | Methods of Applied Mathematics I, II | 1       |
| or APMA 0360| Methods of Applied Mathematics I, II | 1       |
Computer Engineering Track:
The Computer Engineering program is accredited by the Engineering Accreditation Commission of ABET, [http://www.abet.org](http://www.abet.org). The education objectives of the Computer Engineering program are to prepare graduates:
1. to pursue distinctive multidisciplinary scientific and technical careers beginning with either entry-level computer engineering positions in industry or graduate study in computer engineering and related fields;
2. to participate on multidisciplinary teams that cooperate in applying problem-solving skills and critical and independent thinking to a broad range of projects that can produce the technical innovations aimed at satisfying the future needs of society. The student outcomes of this program are the ABET (a) - (k) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at [http://www.abet.org/accreditation-criteria-policies-documents/](http://www.abet.org/accreditation-criteria-policies-documents/)).
The Computer Engineering concentration shares much of the core with the other engineering programs, but is structured to include more courses in computer science, and a somewhat different emphasis in mathematics.

1. Core Courses:

<table>
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<tr>
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<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0030</td>
<td>Introduction to Engineering</td>
<td>1</td>
</tr>
</tbody>
</table>

2. Upper-Level Civil Engineering Curriculum

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1300</td>
<td>Structural Analysis</td>
<td></td>
</tr>
<tr>
<td>ENGN 1340</td>
<td>Water Supply and Wastewater Treatment</td>
<td></td>
</tr>
<tr>
<td>ENGN 1360</td>
<td>Soil Mechanics and Principles of Foundation Engineering</td>
<td></td>
</tr>
<tr>
<td>GEOL 1330</td>
<td>Global Environmental Remote Sensing</td>
<td></td>
</tr>
<tr>
<td>or GEOL 1580</td>
<td>Quantitative Elements of Physical Hydrology</td>
<td></td>
</tr>
<tr>
<td>or GEOL 1590</td>
<td>Quantitative Modeling of Hydrologic Processes</td>
<td></td>
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</tbody>
</table>

3. Civil Engineering Specialty Options (Complete one of the following two course specialty sequences):

3a. Structures

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1380</td>
<td>Design of Civil Engineering Structures</td>
<td></td>
</tr>
<tr>
<td>ENGN 1310</td>
<td>Planning and Design of Systems</td>
<td></td>
</tr>
<tr>
<td>or ENGN 1370</td>
<td>Advanced Engineering Mechanics</td>
<td></td>
</tr>
<tr>
<td>or ENGN 1740</td>
<td>Computer Aided Visualization and Design</td>
<td></td>
</tr>
<tr>
<td>or ENGN 1750</td>
<td>Advanced Mechanics of Solids</td>
<td></td>
</tr>
<tr>
<td>or ENGN 1860</td>
<td>Advanced Fluid Mechanics</td>
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</tbody>
</table>

3b. Environmental Problems

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1130</td>
<td>Phase and Chemical Equilibria</td>
<td></td>
</tr>
<tr>
<td>ENGN 1310</td>
<td>Planning and Design of Systems</td>
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</tbody>
</table>

4. Capstone Design

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1930D</td>
<td>Large Scale Engineering Design Project</td>
<td>1</td>
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</tbody>
</table>

*In addition to program requirements above, students must take four courses in the humanities and social sciences.

Total Credits: 21

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Brown University
The Electrical Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The education objectives of the Electrical Engineering program are to prepare graduates: (1) to pursue distinctive multidisciplinary scientific and technical careers beginning with either entry-level electrical engineering positions in industry or graduate study in electrical engineering and related fields; (2) to participate on multidisciplinary teams that cooperate in applying problem-solving skills and critical and independent thinking to a broad range of projects that can produce the technical innovations aimed at satisfying the future needs of society. The student outcomes of this program are the ABET (a) - (k) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

### 1. Core Courses:
- **ENGN 0030**: Introduction to Engineering
- **ENGN 0040**: Dynamics and Vibrations
- **ENGN 0410**: Materials Science
- **ENGN 0510**: Electricity and Magnetism
- **ENGN 0520**: Electrical Circuits and Signals
- **ENGN 0720**: Thermodynamics
- **ENGN 0310**: Mechanics of Solids and Structures
- **ENGN 0810**: Fluid Mechanics
- **CHEM 0330**: Equilibrium, Rate, and Structure
- **MATH 0190**: Advanced Placement Calculus (Physics/Engineering)
- **MATH 0170**: Advanced Placement Calculus (Physics/Engineering)

### 2. Upper-Level Electrical Engineering Curriculum

#### 2a. Bioelectrical Engineering
- **ENGN 1230**: and one of (ENGN 1220, ENGN 1930B, ENGN 2500 or ENGN 2912L); and one additional course from the following (ENGN 1220, ENGN 1610, ENGN 1930B, ENGN 2500, ENGN 2912L, CLPS 1491, CLPS 1520, NEUR 1680 or NEUR 2110)

#### 2b. Communications Systems
- **ENGN 1580**: and (ENGN 1560 or ENGN 1690); and one additional course from the following (ENGN 1560, ENGN 1610, ENGN 1640, ENGN 1650, ENGN 1690 or ENGN 2530)

#### 2c. Computer Engineering
- **CSCI 0330**: and ENGN 1640; and one additional course from the following (ENGN 1580, ENGN 1600, ENGN 1610, ENGN 1650 or ENGN 2530)

#### 2d. Multimedia Signal Processing
- **ENGN 2530** or **ENGN 1610**; and two additional courses from the following (ENGN 1580, ENGN 1590, ENGN 1600, ENGN 1640, ENGN 1650, ENGN 2500, ENGN 2530, ENGN 2540, ENGN 2560 or CSCI 1230)

#### 2e. Microelectronic Systems
- **ENGN 1600**: ENGN 1640; and one additional course from the following (ENGN 1590, ENGN 1680, ENGN 2530 or ENGN 2912K)

#### 2f. Solid State Electronics and Photonics
- **ENGN 1590**: (ENGN 1560 or ENGN 1690); and one additional course from the following ENGN 1450, ENGN 1560, ENGN 1600, ENGN 1680, ENGN 1931A or PHYS 1420)

#### 2g. Capstone Design
- **ENGN 1650**: Embedded Microprocessor Design or ENGN 1000 Projects in Engineering Design

*In addition to program requirements above, students must take four courses in the humanities and social sciences.

### Total Credits: 21

1. Subject to approval by the concentration advisor, an independent study course (ENGN1970/1971) may be used to fulfill the Engineering Capstone Design requirement. To qualify for such approval, the independent study project must: (1) contain a significant and definable design component; (2) be based on the knowledge and skills acquired in earlier course work, (3) incorporate appropriate engineering standards; and (4) address multiple realistic constraints. To request approval, please complete the online form available at: http://www.brown.edu/academics/engineering/undergraduate-study/
Environmental Engineering Track:
The Environmental Engineering program began in 2013. The program has not been reviewed by ABET and is not ABET-accredited. The education objectives of the Environmental Engineering program are to prepare graduates: (1) to apply in practice the knowledge obtained in school within industry, government, or private practice; (2) to work toward sustainable solutions in a wide array of technical specialties; (3) to pursue lifelong learning through continuing education and/or advanced degrees in environmental engineering. The student outcomes of this program are the (a) - (k) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

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<td>Dynamics and Vibrations</td>
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<tr>
<td>ENGN 0410</td>
<td>Materials Science</td>
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<tr>
<td>BIOL 0200</td>
<td>The Foundation of Living Systems</td>
<td>1</td>
</tr>
<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
<td>1</td>
</tr>
<tr>
<td>ENVS 0490</td>
<td>Environmental Science in a Changing World</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Advanced Placement Calculus (Physics/Engineering)</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0170</td>
<td>Advanced Placement Calculus</td>
<td>1</td>
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<td>or MATH 0200</td>
<td>Intermediate Calculus (Physics/Engineering)</td>
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</tr>
<tr>
<td>or MATH 0180</td>
<td>Intermediate Calculus</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0350</td>
<td>Honors Calculus</td>
<td>1</td>
</tr>
<tr>
<td>APMA 0330</td>
<td>Methods of Applied Mathematics I, II</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 0350</td>
<td>Applied Ordinary Differential Equations</td>
<td>1</td>
</tr>
<tr>
<td>APMA 0650</td>
<td>Essential Statistics</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 1650</td>
<td>Statistical Inference I</td>
<td>1</td>
</tr>
</tbody>
</table>

2. Advance Science Courses

<table>
<thead>
<tr>
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<th>Course Title</th>
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</thead>
<tbody>
<tr>
<td>GEOl 1370</td>
<td>Environmental Geochemistry</td>
<td>1</td>
</tr>
<tr>
<td>or GEOl 1580</td>
<td>Quantitative Elements of Physical Hydrology</td>
<td>1</td>
</tr>
<tr>
<td>BIOL 0415</td>
<td>Microbes in the Environment ( or an approved alternative Natural Science Course)</td>
<td>1</td>
</tr>
<tr>
<td>or BIOL 0420</td>
<td>Principles of Ecology</td>
<td>1</td>
</tr>
</tbody>
</table>

3. Environmental Engineering Specialty Options (Complete one of the following five course sequences)

3a. Chemistry Specialty

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1110</td>
<td>Transport and Biotransport Processes</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1130</td>
<td>Phase and Chemical Equilibria</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1340</td>
<td>Water Supply and Wastewater Treatment</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1710</td>
<td>Heat and Mass Transfer</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1931P</td>
<td>Fuels, Energy, Power and the Environment</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1930U</td>
<td>Renewable Energy Technologies</td>
<td>1</td>
</tr>
</tbody>
</table>

Up to one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0310</td>
<td>Mechanics of Solids and Structures</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
</tr>
</tbody>
</table>

Up to one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSCI 0040</td>
<td>Introduction to Scientific Computing and Problem Solving</td>
<td>1</td>
</tr>
<tr>
<td>or CHEM 0350</td>
<td>Organic Chemistry</td>
<td>1</td>
</tr>
<tr>
<td>or ENVS 1400</td>
<td>Sustainable Design in the Built Environment</td>
<td>1</td>
</tr>
<tr>
<td>or ENVS 1570</td>
<td>Guts of the City: Perspectives on Urban Infrastructure and Environmental Planning (URBN 1570)</td>
<td>1</td>
</tr>
</tbody>
</table>

3b. Energy Specialty

At least three of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1340</td>
<td>Water Supply and Wastewater Treatment</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1710</td>
<td>Heat and Mass Transfer</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1860</td>
<td>Advanced Fluid Mechanics</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1930U</td>
<td>Renewable Energy Technologies</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1931F</td>
<td>Introduction to Power Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1931A</td>
<td>Photovoltaics Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1931P</td>
<td>Fuels, Energy, Power and the Environment</td>
<td>1</td>
</tr>
</tbody>
</table>

Up to one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0310</td>
<td>Mechanics of Solids and Structures</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
</tr>
</tbody>
</table>

Up to one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSCI 0040</td>
<td>Introduction to Scientific Computing and Problem Solving</td>
<td>1</td>
</tr>
<tr>
<td>or ENVS 1400</td>
<td>Sustainable Design in the Built Environment</td>
<td>1</td>
</tr>
<tr>
<td>or ENVS 1570</td>
<td>Guts of the City: Perspectives on Urban Infrastructure and Environmental Planning (URBN 1570)</td>
<td>1</td>
</tr>
</tbody>
</table>

4. Capstone Design

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1000</td>
<td>Projects in Engineering Design</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 1140</td>
<td>Chemical Process Design</td>
<td>1</td>
</tr>
</tbody>
</table>

* In addition to program requirements above, students must take four courses in the humanities and social sciences.

Total Credits: 21

Subject to approval by the concentration advisor, an independent study course (ENGN1970/1971) may be used to fulfill the Engineering Capstone Design requirement. To qualify for such approval, the independent study project must: (1) contain a significant and definable design component; (2) be based on the knowledge and skills acquired in earlier course work, (3) incorporate appropriate engineering standards; and (4) address multiple realistic constraints. To request approval, please complete the online form available at: http://www.brown.edu/academics/engineering/undergraduate-study

Materials Engineering Track:
The Materials Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The education objectives of the Materials Engineering program are to prepare graduates: (1) to pursue multidisciplinary scientific and technical careers beginning with entry-level engineering positions in industry or graduate study in materials science and engineering and related fields; (2) to apply an engineering problem-solving approach combined with a broad appreciation for the liberal arts to inform and develop their understanding of current societal needs and values to achieve leadership positions in their chosen fields of endeavor. The student outcomes of this program are the (a) - (k) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

1. Core Courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0030</td>
<td>Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0040</td>
<td>Dynamics and Vibrations</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0410</td>
<td>Materials Science</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0510</td>
<td>Electricity and Magnetism</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1931P</td>
<td>Fuels, Energy, Power and the Environment</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1930U</td>
<td>Renewable Energy Technologies</td>
<td>1</td>
</tr>
</tbody>
</table>

Up to one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0310</td>
<td>Mechanics of Solids and Structures</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
</tr>
</tbody>
</table>

Up to one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSCI 0040</td>
<td>Introduction to Scientific Computing and Problem Solving</td>
<td>1</td>
</tr>
<tr>
<td>or CHEM 0350</td>
<td>Organic Chemistry</td>
<td>1</td>
</tr>
<tr>
<td>or ENVS 1400</td>
<td>Sustainable Design in the Built Environment</td>
<td>1</td>
</tr>
<tr>
<td>or ENVS 1570</td>
<td>Guts of the City: Perspectives on Urban Infrastructure and Environmental Planning (URBN 1570)</td>
<td>1</td>
</tr>
</tbody>
</table>

* Subject to approval by the concentration advisor, an independent study course (ENGN1970/1971) may be used to fulfill the Engineering Capstone Design requirement. To qualify for such approval, the independent study project must: (1) contain a significant and definable design component; (2) be based on the knowledge and skills acquired in earlier course work, (3) incorporate appropriate engineering standards; and (4) address multiple realistic constraints. To request approval, please complete the online form available at: http://www.brown.edu/academics/engineering/undergraduate-study
### Mechanical Engineering Track:

The Mechanical Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The education objectives of the Mechanical Engineering program are to prepare graduates: (1) to pursue scientific and technical careers beginning with either graduate study in mechanical engineering and related fields or mechanical engineering positions in industry; (2) to work on interdisciplinary teams that make use of the engineering problem solving method and a broad background in the liberal arts to address societal needs. The student outcomes of this program are the (a) - (k) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

<table>
<thead>
<tr>
<th>Total Credits</th>
<th>21</th>
</tr>
</thead>
</table>

1. Core Courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0030</td>
<td>Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0040</td>
<td>Dynamics and Vibrations</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0310</td>
<td>Mechanics of Solids and Structures</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0410</td>
<td>Materials Science</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0510</td>
<td>Electricity and Magnetism</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0720</td>
<td>Thermodynamics</td>
<td>1</td>
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<tr>
<td>ENGN 0810</td>
<td>Fluid Mechanics</td>
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<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Advanced Placement Calculus (Physics/Engineering)</td>
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<tr>
<td>or MATH 0170</td>
<td>Advanced Placement Calculus</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Intermediate Calculus (Physics/Engineering)</td>
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</tr>
<tr>
<td>or MATH 0180</td>
<td>Intermediate Calculus</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0350</td>
<td>Honors Calculus</td>
<td>1</td>
</tr>
<tr>
<td>APMA 0330</td>
<td>Methods of Applied Mathematics I, II</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 0350</td>
<td>Applied Ordinary Differential Equations</td>
<td>1</td>
</tr>
<tr>
<td>APMA 0340</td>
<td>Methods of Applied Mathematics I, II</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 0360</td>
<td>Methods of Applied Mathematics I, II</td>
<td>1</td>
</tr>
<tr>
<td>CHEM 0350</td>
<td>Organic Chemistry</td>
<td>1</td>
</tr>
<tr>
<td>or CSCI 0040</td>
<td>Introduction to Scientific Computing and Problem</td>
<td>1</td>
</tr>
<tr>
<td>or CSCI 0150</td>
<td>Solving</td>
<td></td>
</tr>
<tr>
<td>or CSCI 0170</td>
<td>Introduction to Object-Oriented Programming and</td>
<td></td>
</tr>
<tr>
<td>or CSCI 0190</td>
<td>Computer Science</td>
<td></td>
</tr>
<tr>
<td>or CSCI 0190</td>
<td>Accelerated Introduction to Computer Science</td>
<td></td>
</tr>
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</table>

2. Upper-Level Mechanical Engineering Curriculum

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1410</td>
<td>Physical Chemistry of Solids</td>
<td></td>
</tr>
<tr>
<td>ENGN 1420</td>
<td>Kinetics Processes in Materials Science and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td></td>
</tr>
<tr>
<td>ENGN 1440</td>
<td>Mechanical Properties of Materials</td>
<td></td>
</tr>
<tr>
<td>PHYS 0790</td>
<td>Physics of Matter</td>
<td></td>
</tr>
<tr>
<td>or CHEM 1140</td>
<td>Physical Chemistry: Quantum Chemistry</td>
<td></td>
</tr>
</tbody>
</table>

Three of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1450</td>
<td>Properties and Processing of Electronic Materials</td>
</tr>
<tr>
<td>ENGN 1470</td>
<td>Structure and Properties of Nonmetallic Materials</td>
</tr>
<tr>
<td>ENGN 1480</td>
<td>Metallic Materials</td>
</tr>
<tr>
<td>ENGN 1490</td>
<td>Biopolymers</td>
</tr>
</tbody>
</table>

3. Capstone Design

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0000</td>
<td>Capstone Design</td>
</tr>
</tbody>
</table>

* In addition to program requirements above, students must take four courses in the humanities and social sciences.

---

### Specialty Options (Complete one of the following seven course specialty sequences)

#### 2a. Aerospace Applications

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 0790</td>
<td>Physics of Matter</td>
</tr>
<tr>
<td>ENGN 1370</td>
<td>Advanced Engineering Mechanics</td>
</tr>
<tr>
<td>ENGN 1700</td>
<td>Jet Engines and Aerospace Propulsion</td>
</tr>
<tr>
<td>ENGN 1720</td>
<td>Design of Engines and Turbines</td>
</tr>
<tr>
<td>or ENGN 1760</td>
<td>Design of Space Systems</td>
</tr>
<tr>
<td>ENGN 1860</td>
<td>Advanced Fluid Mechanics</td>
</tr>
</tbody>
</table>

One of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1710</td>
<td>Heat and Mass Transfer</td>
</tr>
<tr>
<td>or ENGN 1300</td>
<td>Structural Analysis</td>
</tr>
<tr>
<td>or ENGN 1740</td>
<td>Computer Aided Visualization and Design</td>
</tr>
<tr>
<td>or ENGN 1750</td>
<td>Advanced Mechanics of Solids</td>
</tr>
</tbody>
</table>

Capstone Design

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1000</td>
<td>Projects in Engineering Design</td>
</tr>
<tr>
<td>or ENGN 1930</td>
<td>Industrial Design</td>
</tr>
<tr>
<td>or ENGN 1931</td>
<td>Design of Mechanical Assemblies</td>
</tr>
</tbody>
</table>

#### 2b. Biomechanics

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 0800</td>
<td>Principles of Physiology</td>
</tr>
<tr>
<td>ENGN 1210</td>
<td>Biomechanics</td>
</tr>
<tr>
<td>ENGN 1230</td>
<td>Instrumentation Design</td>
</tr>
<tr>
<td>ENGN 1370</td>
<td>Advanced Engineering Mechanics</td>
</tr>
</tbody>
</table>

One of the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1700</td>
<td>Jet Engines and Aerospace Propulsion</td>
</tr>
<tr>
<td>or ENGN 1710</td>
<td>Heat and Mass Transfer</td>
</tr>
<tr>
<td>or ENGN 1860</td>
<td>Advanced Fluid Mechanics</td>
</tr>
</tbody>
</table>

One of the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1220</td>
<td>Neuroengineering</td>
</tr>
<tr>
<td>or ENGN 1300</td>
<td>Structural Analysis</td>
</tr>
<tr>
<td>or ENGN 1490</td>
<td>Biopolymers</td>
</tr>
<tr>
<td>or ENGN 1740</td>
<td>Computer Aided Visualization and Design</td>
</tr>
</tbody>
</table>
or ENGN 1750 Advanced Mechanics of Solids
Capstone Design

ENGN 1000 Projects in Engineering Design
or ENGN 1930 Industrial Design
or ENGN 1931 Design of Mechanical Assemblies

2c. Energy Conversion: Fluids and Thermal Systems

PHYS 0790 Physics of Matter
ENGN 1700 Jet Engines and Aerospace Propulsion
ENGN 1710 Heat and Mass Transfer
ENGN 1720 Design of Engines and Turbines
ENGN 1860 Advanced Fluid Mechanics

One of the following courses:
ENGN 1750 Advanced Mechanics of Solids
or ENGN 1300 Structural Analysis
or ENGN 1370 Advanced Engineering Mechanics

Capstone Design
ENGN 1000 Projects in Engineering Design
or ENGN 1930 Industrial Design
or ENGN 1931 Design of Mechanical Assemblies

2d. Engineering Mechanics

PHYS 0790 Physics of Matter
ENGN 1370 Advanced Engineering Mechanics
ENGN 1710 Heat and Mass Transfer
ENGN 1750 Advanced Mechanics of Solids
ENGN 1860 Advanced Fluid Mechanics

One of the following:
ENGN 1300 Structural Analysis
or ENGN 1360 Soil Mechanics and Principles of Foundation Engineering
or ENGN 1420 Kinetics Processes in Materials Science and Engineering
or ENGN 1700 Jet Engines and Aerospace Propulsion
or ENGN 1740 Computer Aided Visualization and Design

Capstone Design
ENGN 1000 Projects in Engineering Design
or ENGN 1380 Design of Civil Engineering Structures
or ENGN 1720 Design of Engines and Turbines
or ENGN 1760 Design of Space Systems
or ENGN 1930 Industrial Design
or ENGN 1931 Design of Mechanical Assemblies

2e. Mechanical Systems: Dynamics, Materials, and Design

PHYS 0790 Physics of Matter
ENGN 1370 Advanced Engineering Mechanics
ENGN 1750 Advanced Mechanics of Solids

One of the following courses:
ENGN 1380 Design of Civil Engineering Structures
or ENGN 1720 Design of Engines and Turbines
or ENGN 1760 Design of Space Systems

One or two of the following courses:
ENGN 1700 Jet Engines and Aerospace Propulsion
or ENGN 1710 Heat and Mass Transfer
or ENGN 1720 Design of Engines and Turbines
or ENGN 1860 Advanced Fluid Mechanics

Capstone Design
ENGN 1000 Projects in Engineering Design
or ENGN 1930 Industrial Design
or ENGN 1931 Design of Mechanical Assemblies
Up to one of the following:
ENGN 1230 Instrumentation Design

or ENGN 1300 Structural Analysis
or ENGN 1380 Design of Civil Engineering Structures
or ENGN 1440 Mechanical Properties of Materials
or ENGN 1620 Analysis and Design of Electronic Circuits
or ENGN 1740 Computer Aided Visualization and Design

2f. Structural Mechanics

PHYS 0790 Physics of Matter
ENGN 1300 Structural Analysis
ENGN 1370 Advanced Engineering Mechanics
ENGN 1710 Heat and Mass Transfer
ENGN 1860 Advanced Fluid Mechanics

One of the following courses:
ENGN 1740 Computer Aided Visualization and Design
or ENGN 1750 Advanced Mechanics of Solids
or ENGN 1760 Design of Space Systems

Capstone Design
ENGN 1380 Design of Civil Engineering Structures

*In addition to program requirements above, students must take four courses in the humanities and social sciences.

Total Credits 21

1 Or another advanced science course, subject to concentration advisor approval.
2 Subject to approval by the concentration advisor, an independent study course (ENGN1970/1971) may be used to fulfill the Engineering Capstone Design requirement. To qualify for such approval, the independent study project must: (1) contain a significant and definable design component; (2) be based on the knowledge and skills acquired in earlier course work, (3) incorporate appropriate engineering standards; and (4) address multiple realistic constraints. To request approval, please complete the online form available at: http://www.brown.edu/academics/engineering/undergraduate-study

3 An ENGN course of equivalent level may be substituted subject to concentration advisor approval.

### Engineering and Physics Concentration Requirements

The Sc.B. program in Engineering and Physics is sponsored jointly by the School of Engineering and the Department of Physics. The program is designed to ensure that students take a significant portion of the usual curriculum in Engineering and in Physics, obtain substantial laboratory experience, and take several upper-level elective courses, focusing on applied science. Students may take either the standard Physics or Engineering programs during their freshman and sophomore years and then switch to this combined program. The Sc.B. degree program in Engineering and Physics is not accredited by ABET.

The following standard program assumes that a student begins mathematics courses at Brown with MATH 0170 or its equivalent. Students who begin in MATH 0200 can substitute an additional science, engineering or higher-level mathematics course for the MATH 0170 or MATH 0190 requirement. To accommodate the diverse preparation of individual students, variations of the following sequences and their prerequisites are possible with permission of the appropriate concentration advisor and the instructors involved. We recommend that each student’s degree program be submitted for prior approval (typically in semester four) and scrutinized for compliance (in semester seven) by one faculty member from the Department of Physics and one faculty member from the School of Engineering.

Select one of the following two course sequences:

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0030</td>
<td>Introduction to Engineering and Dynamics and Vibrations</td>
</tr>
<tr>
<td>&amp; ENGN 0040</td>
<td>Foundations of Mechanics and Foundations of Electromagnetism and Modern Physics</td>
</tr>
<tr>
<td>PHYS 0050</td>
<td>Analysis of Electronic Circuits</td>
</tr>
<tr>
<td>&amp; PHYS 0060</td>
<td>Analytical Mechanics of Rigid Bodies</td>
</tr>
</tbody>
</table>

Brown University
The School of Engineering

Biomedical Engineering Concentration Requirements

The Sc.B. program in Biomedical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/. It is jointly offered by the School of Engineering and the Division of Biology and Medicine as an interdisciplinary concentration designed for students interested in applying the methods and tools of engineering to the subject matter of biology and the life sciences. The education objectives of the Biomedical Engineering program are to prepare graduates: (1) to be employed in careers of useful service to society, including scientific and technical areas within medicine, industry, and health care delivery; (2) to demonstrate the ability to apply the basic principles of engineering and science, as well as problem solving skills and critical thinking, to a broad spectrum of biomedical engineering problems; (3) to demonstrate their ability to work in teams, and to effectively communicate and understand the broad social, ethical, economic and environmental consequences of their lifelong education. The student outcomes of this program are the (a) - (k) Student Outcomes as defined by the “ABET Criteria for Accrediting Engineering Programs (available online at http://www.abet.org/ accreditation-criteria-policies-documents/).” The Biomedical Engineering concentration shares much of the core with the other engineering programs, but is structured to include more courses in biology and chemistry, and a somewhat different emphasis in mathematics.

The requirements regarding Mathematics, Advanced Placement, Transfer Credit, Substitutions for Required Courses, and Humanities and Social Science Courses are identical to those of the Sc.B. degree programs in Engineering. Please refer to the Engineering section of the University Bulletin for explicit guidelines.

The Biomedical Engineering concentration shares much of the core with the other engineering programs, but is structured to include more courses in biology and chemistry, and a somewhat different emphasis in mathematics.

**Standard program for the Sc.B. degree**

1. Core Courses
   - ENGN 0030 Introduction to Engineering 1
   - ENGN 0040 Dynamics and Vibrations 1
   - ENGN 0051 Electricity and Magnetism 1
   - ENGN 0170 Intermediate Calculus (Physics/Engineering) 1
   - ENGN 0810 Fluid Mechanics 1
   - BIOL 0200 The Foundation of Living Systems 1
   - BIOL 0800 Principles of Physiology 1
   - CHEM 0330 Equilibrium, Rate, and Structure 1
   - CHEM 0350 Organic Chemistry 1
   - MATH 0180 Advanced Placement Calculus (Physics/Engineering) 1
   - MATH 0190 Advanced Placement Calculus (Physics/Engineering) 2
   - MATH 0200 Intermediate Calculus (Physics/Engineering) 1
   - MATH 0350 Honors Calculus 1
   - APMA 0330 Methods of Applied Mathematics I, II 1
   - APMA 0350 Applied Ordinary Differential Equations 1
   - APMA 0650 Essential Statistics 1
   - APMA 1650 Statistical Inference I 1

2. Upper Level Biomedical Engineering Curriculum
   - ENGN 1110 Transport and Biotransport Processes 1
   - ENGN 1210 Biomechanics 1
   - ENGN 1230 Instrumentation Design 1
   - ENGN 1490 Biomaterials 1
   - Three Additional Upper Level Biomedical Engineering Courses 3

   Select at least one of the following: 3
   - BIOL 1140 Tissue Engineering
   - or ENGN 1220 Neuroengineering
   - or ENGN 1400 Analytical Methods in Biomaterials
   - or ENGN 1930f Photonics and Biophotonics
   - or ENGN 1930f Molecular and Cell Biology for Engineers
   - or ENGN 2910f Cancer Nanotechnology

   Select at most two of the following: 4
   - BIOL 1150 Stem Cell Engineering
   - or BIOL 1210 Synthetic Biological Systems
   - or BIOL 1800 Animal Locomotion
   - or BIOL 2110 Drug and Gene Delivery
   - or BIOL 2130 Techniques in Molecular and Cell Science

3. Capstone Design 5
   - ENGN 1930L Biomedical Engineering Design, Research and Modeling 1

Total Credits 19

The Biomedical Engineering Design, Research and Modeling course is offered each trimester and consists of five courses. The course is designed to provide an opportunity for students to work with a team of students and faculty to design, develop, and implement a project in the area of biomedical engineering. The course is designed to provide an opportunity for students to work with a team of students and faculty to design, develop, and implement a project in the area of biomedical engineering. The course is designed to provide an opportunity for students to work with a team of students and faculty to design, develop, and implement a project in the area of biomedical engineering.

A thesis under the supervision of a physics or engineering faculty member:

- PHYS 1990 Senior Conference Course
- ENGN 1970 Independent Studies in Engineering
- ENGN 1971 Independent Study in Engineering

* Students are also encouraged to take courses dealing with the philosophical, ethical, or political aspects of science and technology.
The course will begin with a brief history of technology.

Informed opinion on a particular topic of national or international interest.

All educated individuals to understand basic technology and reach an central role of technology on many political issues, and the need for

This course will address the impact that technology has on society, the engineering

http://www.brown.edu/academics/gradschool/programs/biomedical-engineering

For more information on admission and program requirements for the Program in Innovation Management and Entrepreneurship (Sc.MIME); and the Doctor of Philosophy (Ph.D.) in Biomedical Engineering.

For more information on admission and program requirements for the Sc.M. or Ph.D. in Engineering, please visit the following website:

http://www.brown.edu/academics/gradschool/programs/engineering

For more information on admission and program requirements for the Program in Innovation Management and Entrepreneurship Engineering (PRIME), please visit the following website:


For more information on admission and program requirements for Biomedical Engineering, please visit the following website:

http://www.brown.edu/academics/gradschool/programs/biomedical-engineering

**Courses**

**ENGN 0020. Transforming Society-Technology and Choices for the Future.**

This course will address the impact that technology has on society, the central role of technology on many political issues, and the need for all educated individuals to understand basic technology and reach an informed opinion on a particular topic of national or international interest.

The course will begin with a brief history of technology.

| Spr | ENGN0020 S01 24428 MWF 11:00-11:50(04) | J. Harry |
| Spr | ENGN0020 C01 24429 T 10:30-11:50 | J. Harry |
| Spr | ENGN0020 C02 24430 Th 10:30-11:50 | J. Harry |
| Spr | ENGN0020 C03 24431 Th 2:30-3:50 | J. Harry |
| Spr | ENGN0020 C04 24432 T 2:30-3:50 | J. Harry |

**ENGN 0030. Introduction to Engineering.**

An introduction to various engineering disciplines, thought processes, and issues. Topics include computing in engineering, engineering design, optimization, and estimation. Case studies in engineering are used to illustrate engineering fields and scientific principles, including in-depth studies of statics and optics. Laboratories and design projects are included. Prerequisite: one of the following: APMA 0330, 0340, 0350, 0360, MATH 0100, 0170, 0180, 0190, 0200, 0350, 0520, 0540, which may be taken concurrently.

Students MUST register for the course lecture (M01) and one of the sections during the SAME registration session. Banner will not allow a student to register for one component without registering for the other at the same time. Further, if you drop one component of the course on Banner, both components will be dropped.

| Fall | ENGN0030 M01 14843 MWF 1:00-1:50 | C. Briant |
| Fall | ENGN0030 S01 14842 T 9:00-10:20 | C. Briant |
| Fall | ENGN0030 S02 14844 T 2:30-3:50 | C. Briant |
| Fall | ENGN0030 S03 14845 Th 9:00-10:20 | C. Briant |
| Fall | ENGN0030 S04 14846 Th 2:30-3:50 | C. Briant |

**ENGN 0040. Dynamics and Vibrations.**

Study of the kinematics and dynamics of particles and rigid bodies. Principles of motion of mechanical systems. Concepts of inertia, work, kinetic energy, linear momentum, angular momentum, and impact. Applications to engineering systems, satellite orbits, harmonic vibrations of one and two degree of freedom systems. Lectures, recitations, and laboratory. Prerequisite: ENGN 0030. Corequisite: MATH 0200 or 0180.

| Spr | ENGN0040 S01 24433 TTh 9:00-10:20(08) | A. Bower |
| Spr | ENGN0040 C01 24434 MWF 9:00-9:50 | 'To Be Arranged' |
| Spr | ENGN0040 C02 24435 MWF 10:00-10:50 | 'To Be Arranged' |
| Spr | ENGN0040 C03 24436 MWF 11:00-11:50 | 'To Be Arranged' |
| Spr | ENGN0040 C04 24437 MWF 1:00-1:50 | 'To Be Arranged' |
| Spr | ENGN0040 C05 24438 MWF 2:00-2:50 | 'To Be Arranged' |

**ENGN 0090. Management of Industrial and Nonprofit Organizations.**

Exposes students to the concepts and techniques of management. Topics include marketing, strategy, finance, operations, organizational structure, and human relations. Guest lecturers describe aspects of actual organizations. Lectures and discussions.

| Fall | ENGN0090 S02 14836 TTh 2:30-3:50(03) | B. Hazeltine |

**ENGN 0120A. Crossing the Consumer Chasm by Design.**

Technologies have shaped human life since tools were sticks and flints to today's hydrocarbon powered, silicon managed era. Some spread throughout society; bread, cell phones, airlines, but most never do; personal jet packs, Apple Newton, freeze dried ice cream.

Space Tourism, the Segway, electric cars: Can we predict which ones will cross the chasm to broad application? Can we help them to by combining design, engineering, marketing, communications, education, art, and business strategies?

Student teams identify potential new products, conceptualize, package, and define their business mode. By plotting their course across the chasm, we confront the cross-disciplinary barriers to realizing benefits from technology.

Enrollment limited to 18 first year students. Instructor permission required.

| Spr | ENGN0120 S01 24439 MWF 11:00-11:50(04) | R. Fleeter |
ENGN 0120B. Crossing the Space Chasm Through Engineering Design.
Five decades of human activity in space has provided the world community with benefits including instant global communications and positioning, human and robotic exploration of the moon, planets and sun, and a perspective of earth which continues to inform and influence our relationship with our environment.

Unlike other technical revolutions of the 20th century space has not transitioned to a commercial, consumer market commodity. Rather its users and applications remain primarily large and institutional.

To experience the challenges of engineering design and of changing an industrial paradigm, we will work in one or several groups to identify a use of space, and a plan for its implementation, that could help transition space from its status as a niche technology. Through the process of design, we will confront the technical, economic, societal and political barriers to obtaining increased benefits from technologies in general, and space in particular, and to making new technologies beneficial to a wider range of users. Enrollment limited to 18 first year students. Instructor permission required. FYS WRIT

ENGN 0120C. Power: From Early Engines to the Nuclear-Powered Artificial Heart.
Mechanical and electrical power have been source of major changes in civilization in last 250 years. This course starts from introduction to animal muscle power and harnessing nature to steam and later sources of power and applications, examining not only the technologies but also the people who developed them and the social and political impacts, ranging up to the nuclear-powered artificial heart. Enrollment limited to 20 first year students. FYS

ENGN 0120D. Strategies for Creative Process: Design Topics.
There is no one simple methodology for creative thinking. Creative thinking is a critical response to the world around us - to our curiosities and interests, to the questions our observations generate, to the ways we frame problems, and to the strategies we develop for translating what we imagine into objects and experiences. Working as artist/designers, making things within a studio environment, we will examine various approaches for the development and refinement of our creative processes as we establish a technical and conceptual foundation for the design and fabrication of objects and experiences. Enrollment limited to 15 first year students. FYS

ENGN 0130. The Engineer's Burden: Why Changing the World is Difficult.
We will examine the assertion that most of the changes that have improved people's lives are essentially technological and then we will look at the difficulties in creating sustainable and beneficial change. Topics of interest include unintended consequences, failure to consider local culture, and engineering ethics. Many, but not all, of the examples will have a third world context. The engineering focus will be on infrastructure--housing, water and sanitation, transportation, and also mobile devices as used in health care and banking.

ENGN 0230. Surveying.
Theory and practice of plane surveying; use of the tape, level, transit, stadia, and plane table; triangulation and topography. Lectures, field work, and drafting. Recommended for students interested in civil engineering. Hours arranged. Time required, about 10 hours. Audit only.

ENGN 0260. Mechanical Technology.
A basic machine shop course that, with the help of an instructor, teaches students how to fabricate a few simple objects using hand tools and some basic machines. This course is designed to introduce the student to the machining process and environment. Audit only.

Mechanical behavior of materials and analysis of stress and deformation in engineering structures and continuous media. Topics include concepts of stress and strain; the elastic, plastic, and time-dependent response of materials; principles of structural analysis and application to simple bar structures, beam theory, instability and buckling, torsion of shafts; general three-dimensional states of stress; Mohr's circle; stress concentrations. Lectures, recitations, and laboratory. Prerequisite: ENGN 0030.

Fall ENGN0310 C01 14840 T 12:00-12:50 (P. Guduru)
Fall ENGN0310 C02 14841 T 4:00-4:50 (P. Guduru)

ENGN 0410. Materials Science.
Relationship between the structure of matter and its engineering properties. Topics: primary and secondary bonding; crystal structure; atomic transport in solids; defects in crystals; mechanical behavior of materials; phase diagrams and their utilization; heat treatment of metals and alloys; electrical, optical, and magnetic properties of materials; strengthening mechanisms in solids and relationships between microstructure and properties; corrosion and oxidation. Lectures, recitations, laboratory.

Fall ENGN0410 S01 14847 TTh 9:00-10:20(08) (E. Chason)
Fall ENGN0410 S02 15421 M 3:00-5:30(15) (E. Chason)
Fall ENGN0410 C01 15528 W 1:00-1:50 (E. Chason)
Fall ENGN0410 C02 15529 W 3:00-3:50 (S. Kumar)

ENGN 0510. Electricity and Magnetism.
Fundamental laws of electricity and magnetism and their role in engineering applications. Concepts of charge, current, potential, electric field, magnetic field. Resistance, capacitance, and inductance. Electric and magnetic properties of materials. Electromagnetic wave propagation. Lectures, recitation, and laboratory. Prerequisites: ENGN 0030 or PHYS 0070; ENGN 0040 or PHYS 0160 (previously 0080); MATH 0180 or 0200; and APMA 0330 or 0350 (may be taken concurrently).

Fall ENGN0510 S01 14849 MWF 10:00-10:50(14) (J. Beresford)
Fall ENGN0510 C01 14850 T 10:30-11:50 (J. Beresford)
Fall ENGN0510 C02 14851 T 1:00-2:20 (J. Beresford)
Fall ENGN0510 C03 14852 Th 10:30-11:50 (J. Beresford)
Fall ENGN0510 C04 14853 Th 1:00-2:20 (J. Beresford)

ENGN 0520. Electrical Circuits and Signals.
An introduction to electrical circuits and signals. Emphasizes the analysis and design of systems described by ordinary linear differential equations. The frequency domain is introduced, including the effects of sampling and windowing in computer simulations. Other topics include transient analysis, Fourier series, and Laplace transform. Laboratories apply concepts to real problems in audio and controls. Lectures, recitation, and laboratory. Prerequisite: MATH 0180 or MATH 0200, courses may be taken concurrent to ENGN 0520.

Spr ENGN0520 S01 24446 MWF 10:00-10:50(03) (G. Taubin)
Spr ENGN0520 C01 24447 T 9:00-10:20 (G. Taubin)
Spr ENGN0520 C02 24448 T 1:00-2:20 (G. Taubin)
Spr ENGN0520 C03 24449 Th 9:00-10:20 (G. Taubin)
Spr ENGN0520 C04 24450 Th 1:00-2:20 (G. Taubin)

ENGN 0720. Thermodynamics.
An introduction to macroscopic thermodynamics and some of its engineering applications. Presents basic concepts related to equilibrium, and the zeroth, first and second laws for both closed and open systems. Examples include analysis of engines, turbines, and other engineering cycles, phase equilibrium and separation processes, chemical reactions, surface phenomena, magnetic and dielectric materials. Lectures, recitations, and laboratory. Prerequisites: ENGN 0030 or ENGN 0040. Recommended: ENGN 0410 or CHEM 0330.

Spr ENGN0720 S01 24451 TTh 10:30-11:50(09) (A. Peterson)
Spr ENGN0720 C01 24452 W 3:00-3:50 (A. Peterson)
Spr ENGN0720 C02 24453 W 2:00-2:50 (A. Peterson)

Fall ENGN0810 S01 14854 MWF 1:00-1:50(06) (K. Breuer)
Fall ENGN0810 C01 14855 Th 4:00-4:50 (K. Breuer)
Fall ENGN0810 C02 14856 Th 12:00-12:50 (K. Breuer)
Fall ENGN0810 C03 14857 Th 5:00-5:50 (K. Breuer)

ENGN 0900. Managerial Decision Making.
Ways of making effective decisions in managerial situations, especially situations with a significant technological component; decision analysis; time value of money; competitive situations; forecasting; planning and scheduling; manufacturing strategy; corporate culture. Lectures and discussions. Prerequisite: ENGN 0090 or MATH 0100.

Spr ENGN0900 S01 24442 TTh 1:00-2:20(10) (B. Hazeltine)

ENGN 0930A. Appropriate Technology.
Our goal for this course is that you leave it with the ability to think and act rationally and concretely on issues of technology and the human condition. We will provide background on useful technologies (e.g. wind, solar, hydro), techniques to fabricate them, and an opportunity to explore the obstacles to their implementation.

Spr ENGN0930S S01 24444 TTh 10:30-11:50(09) (C. Bull)

ENGN 0930C. Design Studio.
DESIGNSTUDIO is a course open to students interested in learning through making. Working in a studio environment, we will iteratively design, build, and test projects, as we imaginatively frame design problems, and develop novel strategies for addressing those problems. We will explore design thinking, creative collaboration, exploratory play, ideation, iteration, woodworking, prototyping, CNC milling and laser cutting - in addition to other strategies that enhance our creative processes - as we establish a technical and conceptual foundation for the design and fabrication of objects and experiences. Enrollment limited to 16. Instructor permission required.

Spr ENGN0930S C01 24443 TTh 9:00-12:00 (I. Gonsher)

ENGN 0931. Internet of Everything.
The Internet can be visualized as Internet of information, Internet of people, Internet of places and most importantly the Internet of “things.” Internet of Everything includes these four paradigms. In this class, we will learn about how these four ideas can come together to make a difference in the world. We will study the underlying infrastructure that supports Internet, the TCP/IP model, addressing and routing. Experiments and projects in the class would include a tree on the Internet communicating with the sprinkler system only when it is thirsty. Privacy and ethical issues will also be addressed.

Spr ENGN0931 S01 24445 TTh 10:30-11:50(09) (R. Pendse)

ENGN 1000. Projects in Engineering Design.
Projects in design for concentrators in chemical, electrical, materials, and mechanical engineering. Students generally work in teams on projects that are defined through discussions with the instructor. An assembled product or detailed design description is the goal of the semester's effort. Prerequisite: completion of engineering core program. Written permission required.

Fall ENGN1000 S01 14858 MW 3:00-5:20 (J. Fontaine)
Fall ENGN1000 S02 15530 Arranged (I. Gonsher)
Spr ENGN1000 S01 24454 M 3:00-5:30(13) (J. Fontaine)

Entrepreneurship is innovation in practice: transforming ideas into opportunities, and, through a deliberate process, opportunities into commercial realities. These entrepreneurial activities can take place in two contexts: the creation of new organizations; and within existing organizations. This course will present an entrepreneurial framework for these entrepreneurial processes, supported by case studies that illustrate essential elements. Successful entrepreneurs and expert practitioners will be introduced who will highlight practical approaches to entrepreneurial success. Enrollment limited to 35. WRIT

Fall ENGN1010 S01 14859 TTh 10:30-11:50(13) (D. Warshay)
Fall ENGN1010 S02 14860 M 6:00-8:30PM (J. Cohen)
Fall ENGN1010 S03 14861 TTh 2:30-3:50(03) (J. Harry)
Spr ENGN1010 S01 24455 TTh 9:00-10:20(08) (B. McNally)
Spr ENGN1010 S02 24456 TTh 10:30-11:50(09) (D. Warshay)

ENGN 1110. Transport and Biotransport Processes.
Aim: To develop a fundamental understanding of mass transport in chemical and biological systems. The course includes: mechanism of transport, biochemical interactions and separations; mass transport in reacting systems; absorption; membrane and transvascular transport; electrophoretic separations; pharmacokinetics and drug transport; equilibrium stage processes; distillation and extraction. Other features: design concepts; modern experimental and computing techniques; laboratory exercises.

Spr ENGN1110 S01 24458 TTh 2:30-3:50(11) (A. Shukla)

ENGN 1120. Chemical and Biochemical Reactor Design.
Stoichiometry, thermodynamics, mechanisms, and rate expressions of homogeneous and heterogeneous chemical and biochemical systems. Basic concepts in homogeneous chemical and bioreactor design and ideal reactor models. Chemostats and enzymatic reactors. Optimization. Temperature and energy effects in reactors. Introduction to heterogeneous chemical and bioreactor design. Prerequisite: ENGN 0720 or physical chemistry. Offered in alternate years.

Fall ENGN1120 S01 15422 TTh 1:00-2:20(10) (P. Chen)

ENGN 1130. Phase and Chemical Equilibria.
Application of the first and second laws of thermodynamics and conservation of mass to the analysis of chemical and environmental processes, phase and chemical equilibria and partitioning of species in multiphase, nonreactive and reactive systems. Thermodynamic properties of fluid mixtures-correlation and estimation. Applications and examples drawn from chemical processing and environmental problems. Prerequisite: ENGN 0720.

ENGN 1140. Chemical Process Design.
Chemical process synthesis, flow charting, and evaluation of design alternatives. Process equipment sizing as determined by rate phenomena, economics, and thermodynamic limitations. Introduction to optimization theory. Applications of these principles to case studies. Prerequisites: ENGN 1110, 1130; ENGN 1120 (may be taken concurrently).

Spr ENGN1140 S01 24459 TTh 6:40-8:00PM(12) (M. Wojtczak)

ENGN 1210. Biomechanics.

Spr ENGN1210 S01 24460 MWF 2:00-2:50(07) (T. Powers)
ENGN 1220. Neuroengineering
Course Goals: To develop an advanced understanding of how signals are generated and propagated in neurons and neuronal circuits, and how this knowledge can be harnessed to design devices to assist people with neurologic disease or injury. Fundamental topics in neuronal and neural signal generation, recording methods, and stimulation methods. Clinical/Translational topics include multiple clinically available and emerging neuretechnologies. Prerequisites: NEUR 0010 and ENGN 0510; or instructor permission, which may be provided after discussion with course faculty.
Spr ENGN1220 S01 24461 TTh 1:00-2:20(10) (L. Hochberg)

ENGN 1230. Instrumentation Design
Sensors for pressure, temperature, blood flow, muscle and neural activity. Amplifiers, filters, and A/D/D/A converters. The use of computers in monitoring and controlling physiological processes. Feedback controllers for temperature, flow rate, and experimental stimuli. Intended as a design course primarily for biomedical engineers. Lab times to be arranged. WRIT Fall ENGN1230 S01 14862 MWF 10:00-10:50(14) (D. Borton)

ENGN 1300. Structural Analysis
A unified study of truss, beam, frame, plate, and shell structures. Emphasis on principles of virtual work and numerical methods of elastic structural analysis by matrix methods. Includes calculation of deflections and reactions in beam structures, beam vibrations, and column buckling. Theorems of plastic limit analysis. Plate bending. Membrane stresses and local bending effects in axially symmetric shells. Prerequisite: ENGN 0310.
Spr ENGN1300 S01 24464 MWF 9:00-9:50(02) (H. Kesari)

ENGN 1310. Planning and Design of Systems
No description available.

ENGN 1340. Water Supply and Wastewater Treatment
The hydrological cycle, surface water hydrology, ground water hydrology. Emphasis on the formulation of mathematical models of various flow problems and their solution by analytical or numerical means. Typical problems: open channel and river flows; flood routing; ground water flow in aquifers and into wells. Topics in wastewater treatment plant design: mixing, residence time, aeration, and, bacteriological and chemical treatment processes. Prerequisite: CHEM 0330 and MATH 0170 or MATH 0190. Not open to first year students. Enrollment limited to 40.
Spr ENGN1340 S01 24463 W 3:00-5:30(14) (I. Kulaots)

Classification and identification of geological materials; mechanical and physical properties and methods of testing. Elements of the analysis of stress and strain in rock and soil masses; theories of failure, theory of seepage. Problems of building foundations; consolidation and settlement; stability of earth slopes and embankments. Includes geotechnical laboratory. Prerequisite: ENGN 0310.

A unified study of the dynamics of particles, rigid bodies, and deformable continua. Generalized coordinates and Lagrange's equations; variational principles; stability of equilibrium; vibrations of discrete systems and of elastic continua, and wave propagation. Prerequisites: ENGN 0040, APMA 0340, or equivalent.
Spr ENGN1370 S01 24465 TTh 9:00-10:20(08) (H. Gao)

ENGN 1380. Design of Civil Engineering Structures.
This course provides an introduction to the design of steel and reinforced concrete structures using ultimate strength methods. Lectures will cover key concepts of design theory, building codes, and standards using examples from real structures. Students will apply concepts through computer labs, homework problems, and a design project. Lectures plus lab. Prerequisite: ENGN 1300.
Fall ENGN1380 S01 14863 TTh 6:40-8:00PM(05) 'To Be Arranged'

ENGN 1400. Analytical Methods in Biomaterials.
Analytical methods and instrumentation currently used to characterize biomaterials. Specific methods/instrumentation covered include: molecular scale analysis (NMR, FTIR, UV-Vis spectroscopy); surface analysis (AFM, SEM, XPS, contact angle goniometry, ellipsometry, quartz crystal microbalance, electrochemistry, grazing angle IR); bulk analysis (DSC, mechanical testing) and biological analysis (bioassays, fluorescence and confocal microscopy). Prerequisites: CHEM 0330, CHEM 0350, ENGN 0040 and BIOL 0200. Enrollment limited to 40.

ENGN 1410. Physical Chemistry of Solids.
Application of physical chemistry and solid state chemistry to the structure and properties of engineering solids as used in solid state devices, ceramics, and metallurgy. Equilibrium and free energy of heterogeneous systems, thermodynamics of solutions, chemical kinetics, diffusion, catalysis and corrosion, solid state transformations. Case studies taken from industrial practice. Prerequisites: ENGN 0410, 0720.
Fall ENGN1410 S01 14864 MW 4:30-5:50 (A. Van De Walle)

This course introduces the basic principles and formulations that describe kinetic processes in materials science and engineering. These are divided into the following principle types of mechanisms: solid state diffusion, reactions at surfaces and interfaces, and phase transformations. The final section of the course applies these principles to several relevant materials processing systems. Prerequisites: ENGN 0410, 0720, 1410 or equivalent.
Spr ENGN1420 S01 24466 TTh 9:00-10:20(08) (B. Sheldon)

Focuses on the science of electronic materials, the materials at the heart of modern microelectronics and optoelectronics. Addresses fundamental issues controlling their properties, processing, and reliability. Topics include band structure of semiconductors, basic devices structures (junctions and transistors), sputter deposition, molecular beam epitaxy, chemical vapor deposition, ion implantation, oxidation, and issues affecting reliability. Materials challenges that must be resolved for future generations of electronic devices.
Spr ENGN1440 S01 24467 TTh 1:00-2:20(10) (E. Chason)

A study of the structure and properties of nonmetallic materials such as glasses, polymers, elastomers, and ceramics. The crystal structure of ceramics and polymers, and the noncrystalline networks and chains of glasses, polymers, and elastomers and the generation of microstructures and macrostructures are considered. The mechanical, chemical, electrical, magnetic, and optical properties and their dependence on structure are developed. Laboratory. Prerequisite: ENGN 0410.
Fall ENGN1470 S01 15427 TTh 6:40-8:00PM(05) (G. Palmore)
Spr ENGN1470 S01 24468 TTh 6:40-8:00PM(12) (G. Palmore)

ENGN 1480. Metallic Materials.
The microstructure of metals, microstructural evolution during processing, and the relationships between the microstructure and the physical properties of the material. Crystallography and x-ray diffraction. Crystalline defects, dislocations, grain boundaries, and their effects on mechanical and other properties. Solid state diffusion and solid state phase transformations. Oxidation and corrosion. Laboratory. Prerequisite: ENGN 0410, 1410.
ENGN 1490. Biomaterials.
Biomaterials science, the study of the application of materials to problems in biology and medicine, is characterized by medical needs, basic research, and advanced technological development. Topics covered in this course include materials used in bone and joint replacement, the cardiovascular system, artificial organs, skin and nerve regeneration, implantable electrodes and electronic devices, drug delivery, and ophthalmology.
Fall ENGN1490 S01 14865 MWF 2:00-2:50(07) (L. Wong)

ENGN 1510. Nanoengineering and Nanomedicine.
Students in this course will develop a fundamental understanding of nanoengineering and its applications in medicine. We will discuss nanomaterials synthesis, fabrication, and characterization. Applications of nanoengineered materials in medicine, including nanotechnology-based drug delivery systems, nano-based imaging and diagnostics, and nanotechnology-based tissue engineering approaches will be explored in depth. Host response to nanomaterials and nanotoxicology will also be discussed. Research methods in nanotechnology and nanomedicine will be emphasized (i.e. critical analysis of scientific literature, effective oral and written communication). This course is meant for engineering and science graduate students and advanced upper level engineering undergraduates.
Fall ENGN1510 S01 16572 TTh 1:00-2:20(10) (A. Shukla)

ENGN 1520. Cardiovascular Engineering.
In this course, students will learn quantitative physiological function of the heart and vascular system, including cardiac biomechanics and vascular flow dynamics, through lectures and discussion of current scientific literature. A systems approach will integrate molecular biophysics, cell biology, tissue architecture, and organ-level function into a quantitative understanding of health and disease. Discussion topics will include cardiovascular devices, pre-clinical regenerative therapies, stem cell ethics, and clinical trials. WRIT
Fall ENGN1520 S01 14866 MWF 2:00-2:50(07) (K. Coulombe)

A first course on electromagnetic waves and photonics. Topics to be covered include basic wave phenomena with an emphasis on geometric optics, the interaction of light with matter, scattering, and interference and diffraction effects. Also covered will be a selected number of more advanced topics including laser physics, nonlinear optics, transmission lines, and antennas.

ENGN 1570. Linear System Analysis.
Analysis of discrete and continuous electrical signals and systems in both time and frequency domains. Modulation, sampling, spectral analysis, analog and digital filtering, Fourier, Laplace and z-transforms, the state-space approach, stability of linear systems. Prerequisite: ENGN 0520. Fall ENGN1570 S01 14867 MWF 1:00-1:50(06) (B. Kimia)

ENGN 1580. Communication Systems.
We will learn basic communication and information theory, but with examples drawn from a variety of areas not normally considered communication. Basic knowledge of Laplace/Fourier transforms and frequency domain is essential (ENGN 0520 or equivalent required). Linear Systems (ENGN 1570). Probability (APMA 1650 or MATH 1610). Linear Algebra (MATH 0520 or 0540) and E&M (ENGN 0510) are helpful but not required. Analog modulation, digitization, signal space, digital modulation and noise, information theory, selected topics in modern communication/information network theory and applications to biology and physics as time and interest permit. Depending on preparation, we may also pursue final projects.

ENGN 1590. Introduction to Semiconductors and Semiconductor Electronics.
An introduction to the physics of fundamental electronic processes that underlie the operation of semiconductor devices on a microscopic scale. Basic electronic properties of semiconductors and effects at interfaces heterogeneous media, such as pn junctions and hetero-structure barriers and quantum wells. These junctions, barriers and wells are used as building blocks for devices, focusing on bipolar and field-effect transistors. Modern trends in micro- and opto-electronic devices are discussed. A brief fabrication lab will introduce pn junction fabrication technology. Prerequisites: ENGN 0410 and 0510.
Fall ENGN1590 S01 14868 MWF 10:00-10:50(14) (A. Zaslavsky)

ENGN 1600. Design and Implementation of Very Large-Scale Integrated Systems.
VLSI (Very Large Scale Integration) CMOS (Complementary Metal Oxide Semiconductor) technology is the main driver of our digital revolution. The goal of the course is to learn how to design and implement VLSI digital circuits and optimize them with respect to different objectives such as area, speed, and power dissipation. Design and analysis will be carried out using computer-aided tools. Prerequisite: ENGN 1630, or instructor permission.
Fall ENGN1600 S01 15429 MW 8:30-9:50(01) (S. Reda)

ENGN 1610. Image Understanding.
Image processing is a technology experiencing explosive growth; it is central to medical image analysis and transmission, industrial inspection, image enhancement, indexing into pictorial and video databases, e.g., WWW, and to robotic vision, face recognition, and image compression. This senior-level undergraduate course covers theoretical underpinnings of this field and includes a series of practical MATLAB image processing projects. ENGN 1570 is recommended but not required.
Fall ENGN1610 S01 14869 MWF 2:00-2:50(07) (P. Felzenszwalb)

Elementary device physics and circuit characteristics of semiconductor diodes, bipolar junction transistors (BJTs), and field effect transistors (FETs). Analysis and design of practical circuits using discrete semiconductor devices. Constraint on and techniques for linear integrated circuit (IC) design and the use of linear ICs as circuit building blocks. Laboratory. Prerequisites: ENGN 0510, 0520 or equivalent.
Spr ENGN1620 S01 24469 MWF 2:00-2:50(07) (D. Durfee)

ENGN 1630. Digital Electronics Systems Design.
Fundamentals of digital logic design including: Boolean algebra, gates, truth tables, logic families, flip-flops, finite state machines, memory, and timing. More advanced topics include A-D conversion, binary arithmetic, CPU organization, programmable logic (CPLDs and FPGAs), and VHDL. Extensive laboratory requirement. Not open to first year students; permission required for sophomores.
Fall ENGN1630 S01 14870 WF 3:00-4:20 (W. Patterson)

This course introduces the main concepts and techniques for designing computing systems. Topics covered include assembly language, instruction set design, pipelining, superscalar and VLIW processor design, memory subsystem design, and I/O interfacing. Laboratory topics include programmable logic devices, hardware definition languages, and implementation of a bootable version of the pipelined MIPS processor. Laboratory emphasizes design optimizations with respect to speed and design area. Prerequisite: ENGN 1630 or passing of a quiz on basic digital logic concepts, or instructor permission.
Spr ENGN1640 S01 24470 MWF 10:00-10:50(03) (R. Bahar)
ENGN 1650. Embedded Microprocessor Design. This is a combined lecture and design project course offering experience in the open-ended design of an electronic product or system employing an embedded microprocessor by small-group design teams. Activity includes product specification, circuit design, programming, printed circuit layout, construction, packaging, and economic assessment. Teams are expected to produce functional products. Lecture topics will be adjusted to reflect the chosen design problems. Emphasis is placed on the criteria for choosing processors and on the interfaces and programming requirements of the system. Primarily for senior concentrators. Experience with C programming is helpful but not required. Prerequisite ENGN 1630 or permission of the instructor.

ENGN 1660. Design and Fabrication of Semiconductor Devices. Contemporary practice in the design and fabrication of semiconductor devices. The realization of basic electronic device functions on the semiconductor platform is a central theme in a coordinated lecture and laboratory course. Topics include microcrircuit photolithography; layout and design scaling rules for integrated circuits; and techniques in semiconductor and thin film processing as they apply to ULSI circuit manufacturing. Prerequisite: ENGN 1590 or permission. Spr ENGN1660 S01 14871 TTh 10:30-11:50(13) (W. Patterson)

ENGN 1680. Design and Fabrication of Semiconductor Devices. Contemporary practice in the design and fabrication of semiconductor devices. The realization of basic electronic device functions on the semiconductor platform is a central theme in a coordinated lecture and laboratory course. Topics include microcrircuit photolithography; layout and design scaling rules for integrated circuits; and techniques in semiconductor and thin film processing as they apply to ULSI circuit manufacturing. Prerequisite: ENGN 1590 or permission. Spr ENGN1680 S01 24471 MW 9:00-9:50(02) (D. Pacifici)

ENGN 1690. Photonics and Applications. Science and engineering principles of photonics and optoelectronics, that provide foundation to a broad range of technologies from internet to lighting, from lasers to DVD, from satellite images to computer display, from solar cells to single molecule detection. Topical content: light as waves in media, on surface, and through holes; interference and waveguiding; light generation by spontaneous emission or by stimulation; LED, Laser, Photodetector, Optical amplifier and modulator, etc. Prerequisite: ENGN 0510 or equivalent. Spr ENGN1690 S01 24472 TTh 2:30-3:50(11) (J. Xu)

ENGN 1700. Jet Engines and Aerospace Propulsion. Dynamics and thermodynamics of compressible internal flows with applications to jet engines for both power and propulsion, rocket engines and other propulsion systems. Thermodynamic analyses of engine cycles with and without afterburners. Fluid dynamics of high Mach number systems. Structural and Materials considerations for engine design. Team projects for analysis and design of novel jet engine concepts. Prerequisite: ENGN 0720 and 0810. Fall ENGN1700 S01 15430 MWF 11:00-11:50(02) (J. Liu)


ENGN 1740. Computer Aided Visualization and Design. Provides instruction in the application of computers to the design methods in engineering. Hands-on experience in use of CAD/CAE software packages for geometric modeling, visualization, and drafting. Emphasis on applications to solids and structural problems. Independent design projects are carried out. Course counts as an ABET upper-level design course for mechanical and civil engineering concentrators. Prerequisite: ENGN 0310. Spr ENGN1740 S01 24474 TTh 6:40-8:00PM(12) (B. Burke)


ENGN 1760. Design of Space Systems. Working in design groups, students conceive a space mission and design all of the elements necessary for its execution including launch and orbit / trajectory, space and ground systems, including analysis of structure, thermal, radio link, power and mass budgets, attitude control and dynamics. Each group builds a hardware project to demonstrate a core element of their mission design. Prerequisites: Engineering core curriculum or equivalent Spr ENGN1760 S01 24476 MWF 1:00-1:50(06) (R. Fleeter)

ENGN 1860. Advanced Fluid Mechanics. Aims to give mechanical engineering students a deeper and more thorough grounding in principles and basic applications. Topics include review of the conservation principles; inviscid flow; viscous flow, including aerodynamics lubrication theory; laminar boundary layers; wave motions and wave drag. Lectures, assignments, computational projects, and laboratory. Prerequisites: ENGN 0720 and 0810. Spr ENGN1860 S01 24476 MW 11:00-11:50(04) (J. Franck)

ENGN 1900. Construction of the Entrepreneurial Enterprise Framework:Frm Decision Making to Opportunity Creation. Students examine and engage with the decision making process in the modern enterprise, including investment, negotiation, and opportunity creation. This is done in an entrepreneurial context. Teams research and present orally and in writing on major class themes. Case studies. Socratic discussion models, readings, guest lectures, rhetoric and writing fellow's support for videotaped oral and written business plans are utilized. Enrollment limited to 35.

ENGN 1930A. 3D Photography. By 3D photography we refer to a number of processes that use cameras and lights to capture the shape and appearance of 3D objects. In this course we will first study and build basic 3D techniques and systems, and then cover several closely related methods based on signal processing techniques, constrained energy minimization, and the solution of diffusion differential equations to smooth, denoise, edit, compress, transmit, simplify, and optimize very large polynomial models. Applications include computer animation, game development, electronic commerce, heritage preservation, reverse engineering, and virtual reality.

ENGN 1930B. Photonics and Biophotonics. Biomedical optics is a rapidly growing field with applications in medicine, biology, neuroscience, genetics, and environmental science. The course covers both theoretical background and technical approaches underlying biomedical imaging technologies. The theoretical background focuses on how photons transport in biological tissues, including the radiative transport equation and photon diffusion theory. The course offers not only mathematical fundamentals of the theories but also opportunities of learning the theories through numerical simulations on MATLAB. The technical approaches include those for various imaging technologies ranging from conventional microscopy to optical coherence tomography. Prerequisites: Undergraduate level ENGN 0510 Minimum Grade of S . Spr ENGN1930B S01 24462 MW 12:00-12:50(05) (J. Lee)

ENGN 1930D. Large Scale Engineering Design Project. Provides a major design experience for civil, mechanical, and, with approval, environmental engineering students. This experience involves an open-ended design problem that requires teamwork and the integration of understanding developed in upper-level courses in the engineering concentrations. Intended for students in their senior year.
ENGN 1930F. Entrepreneurship and Good Work: Engineering Dreams.
In this course, students examine the concepts of creation, organization, promotion, management and risk of ownership, to wit: entrepreneurship. This is done in the context of 'good work'. Using a combination of relevant case studies, readings, guest lectures and discussion, each participant builds a theory and framework to explore what defines innovative and meaningful engagement during one's working years. Enrollment limited to 24. Written permission required.

ENGN 1930G. Entrepreneurship I.
Teams of students from Engineering, COE and other technical and non-technical disciplines form simulated high tech startup companies working on mentor-defined opportunities, from conception to commercialization. Intellectual property, marketing, definition of a product requirements document, human factors (including team building), safety and environmental concerns, and legal concerns are emphasized. Students in the COE Technology Management Track should complete ENGN 1010 prior to this course. Enrollment in the course is limited and students must fill out a formal application (though COE tech track seniors are automatically approved). The course meets TR from 2:30-3:50, and other outside meeting hours will be arranged. WRIT

ENGN 1930H. Entrepreneurship II.
Please see ENGN 1930G for course description. Enrollment limited to 24. WRIT

ENGN 1930I. Ethics and Professionalism.
Issues of ethics and professionalism for the engineer and for members of other professions. The principal objectives are to examine the responsibility a person accepts when practicing his or her profession and to provide opportunities for students to explore the ethical aspects of their profession, become comfortable and confident discussing and using value systems, and practice effective expression of ideas in oral and written form.

ENGN 1930K. High-Performance Sensors and Multimedia.
Design, construction, and programming of embedded systems with system-on-chip processors, and audio/visual sensors for real-time applications. Design and implementation of distributed audio/visual applications. Hands-on project oriented hardware/software course.

ENGN 1930L. Biomedical Engineering Design, Research and Modeling.
This course introduces students to design, modeling and analysis of biological systems. The first portion of the course focuses on linear systems. Research projects in design will be analyzed. The course also introduces students to the Matlab programming language, which allows them to implement the design models discussed in class. For seniors only. Fall ENGN1930L S01 14873 MW 8:30-9:50(01) (A. Tripathi)

ENGN 1930M. Industrial Design.
Brown engineering and RISD industrial design faculty lead product development teams through a design cycle. Engineers explore industrial design, designers gain some insight into engineering, and both groups can apply their skills to challenging problems. Frequent presentations, field trips, critiques, and labs. Preference given to seniors. Prerequisites: completion of engineering core. Enrollment limited to 15 students. Fall ENGN1930M S01 14874 Arranged (C. Bull)

ENGN 1930N. Introduction to Magnetic Resonance Imaging and Neuroimaging.
Magnetic resonance imaging (MRI) is a powerful tool for investigating the biological structure and functional dynamics across an incredibly broad spatial and temporal scale. This course will provide an understanding of the basic physical principles of magnetic resonance; including signal generation, detection and contrast mechanisms; as well as image acquisition techniques and reconstruction methods. This course is aimed at undergraduate and graduate students from a variety of disciplines, including: Engineering, Computer Science, Applied Mathematics, Physics, Cognitive Science and Neuroscience as well as medical students and residents. Students should have a basic understanding of matrix mathematics and familiarity with the concepts of magnetism and waves.

Integrated analysis and design of MicroElectroMechanical Systems (MEMS), which are highly integrated micron-scale devices used in many applications: sensors, energy (engines), optics, bioengineering, chemical processing, etc. Provides an introduction to the science and art of design, fabrication, performance, and use of MEMS in all disciplines of engineering.

ENGN 1930P. Solid Biomechanics.
Applications of mechanics to biological systems over a range of scales, including microscopic scales of cells and cellular components, intermediate scales of tissues and muscles, and macroscopic scales of organs, joints, locomotion, and whole organisms. Dimensional analysis and scaling; elasticity, viscoelasticity, poroelasticity applied to tissue mechanics; models for muscle contraction; mechanics of the cytoskeleton, biopolymers, cell membranes, and cell adhesion. Prerequisites: ENGN 0040 or equivalents, APMA 0330.

ENGN 1930Q. Molecular and Cell Biology for Engineers.
Applications of mechanics to biological systems over a range of scales, including microscopic scales of cells and cellular components, intermediate scales of tissues and muscles, and macroscopic scales of organs, joints, locomotion, and whole organisms. Dimensional analysis and scaling; elasticity, viscoelasticity, poroelasticity applied to tissue mechanics, models for muscle contraction; mechanics of the cytoskeleton, biopolymers, cell membranes, and cell adhesion. Prerequisites: ENGN 0040 or equivalents, APMA 0330.

ENGN 1930S. Land Use and Built Environment: An Entrepreneurial View.
Through the use of readings, group discussions, students presentations and guest lectures, students examine and challenge the analytical and structural frameworks which underlie and support public and private land and use the urban and suburban built environments. Students build an understanding and theory of how social, political, governmental and economic forces interact with society's present and future physical space needs.

ENGN 1930T. Vehicle Design.
No description available.

ENGN 1930U. Renewable Energy Technologies.
Analysis of the thermodynamics, physics, engineering and policy issues associated with renewable and non-renewable energy technologies with applications appropriate to both the developed and the developing world. Specific technologies that will be studied include Fossil fuels, Wind, Solar, Hydro, Biomass and Nuclear. Energy consumption technologies, such as power generation and transportation will also be studied. Some technical background, such as ENGN 0030, 0040 and 0720, is strongly recommended. Spr ENGN1930U S01 24477 TTh 2:30-3:50(11) (K. Breuer)

ENGN 1930W. The Art and Science of Light.
This studio course explores artificial light from both artistic and scientific perspectives. Laboratory demonstrations on optics and new light emitting materials will be counterbalanced by presentations on the historical and contemporary integration of these materials within the fields of architecture, industrial design, and sculpture. Students will be asked to reimagine the light bulb by developing artistic design alternatives to conventional lighting. Extensive outside work is expected. Written permission required.
Taught via Socratic method, this course will use case studies that explore essential elements of the entrepreneurial process: Defining Entrepreneurship; Recognizing Opportunities and Developing Business Models; Assembling The Team; Raising Financial Resources; Managing Uncertainty; Managing the Growing Venture; and Realizing Value. Guests will include successful entrepreneurs and expert practitioners who will highlight practical approaches to entrepreneurial success.

Please note that beginning with the very first class, students MUST read the session's case study and supplemental readings, to be ready for participation in discussions. For the first day's assignment, please contact Professor Warshay directly at Daniel_Warshay@brown.edu. Enrollment limited to 35. WRIT

ENGN 1930Y. Social Enterprises.
eThis course will combine reading, discussion, field work, and guest talks by practitioners and theorists to delve into the workings of a variety of social enterprise models. Prerequisites: Social Entrepreneurship (ENGN1930Q) or comparable experience and an existing relationship with a social enterprise.

ENGN 1930Z. Robot Design.

ENGN 1931A. Photovoltaics Engineering.
This seminar course will provide an overview of the operation, design, characterization, and manufacturing of photovoltaic solar cells and panels. The course will span a range from the fundamental physics of solar cell operation to highly applied, industrially relevant engineering topics. Recommended prerequisites: Good knowledge of basic physics and electromagnetism concepts; proficiency in ENGN 0510 or PHYS 0470.
This course is designed for undergraduate and graduate students in Physics, Chemistry and Engineering interested in the field of alternative energy with a focus in photovoltaics. Enrollment limited to 20.

ENGN 1931D. Design of Mechanical Assemblies.
An introduction to the design and development of mechanical assemblies suitable for production over a range of volumes, from prototypes to high volume manufacture. The course is intended to present an overview of basic machine components and manufacturing processes from the perspective of a design engineer in a contemporary industrial setting. The objective of which being to provide students the background necessary to create mechanical assemblies from blank-page concepts through to production ready designs. Coursework will include both theoretical and experimental exercises as well as two group projects working on a mechanical assembly produced via high volume manufacture.
Prerequisite: ENGN 0310, 1740. Enrollment limited to 20.

Fall ENGN1931D S01 14876 TTh 6:40-8:00PM(05) (B. Burke)

ENGN 1931E. Writing Science.
This seminar focuses on communicating scientific and technical information to a lay audience in ways that engage and inform. The focus is on writing about new findings, scientific disputes and policy debates, along with producing profiles, feature articles, op-eds and blog posts. Students who complete this seminar will learn how to turn a collection of facts into a story, ways of explaining complex topics in simple terms, and how to differentiate between crucial technical details and clutter. Proficiency in English is assumed. Permission from the instructor is required. Preference will be given to seniors and graduate students. Enrollment limited to 15. WRIT

Fall ENGN1931ES01 14877 W 3:00-5:30(17) (C. Dean)

ENGN 1931F. Introduction to Power Engineering.
An introduction to the generation, distribution and use of electrical energy in three-phase balanced systems. Topics include: properties of magnetic fields and materials; magnetic reluctance circuits; phasors and the properties of balanced three-phase voltage and current lines; generators; transformers and transmission lines; induction motors; brushless DC motors; power semiconductor switches; and the properties of solar photovoltaic sources and microinverters. Laboratory project. Prerequisites: ENGN 0510 and 0520.
Spr ENGN1931F S01 24478 MWF 1:00-1:50(06) (W. Patterson)

The course will explore where the majority of "useful" energy originates today. Main fossil energy sources (e.g., coal, crude oil, gas, shale oil, tar sands) and their chemical characteristics will be considered. Environmental aspects of fuel production (mining, drilling), fuel conversion technologies, both for delivering heat and power, and why there are limitations on the conversion to the latter. Calculations of "carbon footprint" will be illustrated. Common examples of emissions control technologies, including carbon capture and sequestration, will be presented. Policy and social implications of these energy issues will be discussed. Prerequisites: CHEM 0330 and ENGN 0720.
Fall ENGN1931P S01 14878 TTh 10:30-11:50(13) (I. Kulaots)

ENGN 1931Z. Interfaces, Information & Automation.
Laboratory-intensive course to help students develop and implement simple computer programs in Python to control, query, and integrate discrete (traditionally isolated) systems, ranging from automobiles to websites. Assignments will provide hands-on practice using programmatic interfaces to control both physical and virtual systems. Topics include physical interfaces and communication protocols (e.g., GPIB, RS-232, USB) as well as accessing online resources (e.g., SOAP and RESTful web services) and building hybrid systems for data acquisition and analysis. Formal programming experience is not required, but familiarity with either MatLab or Python (at the level of CSCI0040 or higher) would be very helpful.
Fall ENGN1931Z S01 16141 MWF 11:00-11:50(02) (R. Zia)

Independent Study in Engineering. Instructor permission required after submitting online proposal (http://brown.edu/academics/engineering/content/independent-study). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.
Independent Study in Engineering. Instructor permission required after submitting online proposal (http://brown.edu/academics/engineering/content/independent-study). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

Interested students must register for PHYS 2020.
Fall ENGN2010 S01 16708 Arranged "To Be Arranged"

An introduction to methods of mathematical analysis in physical science and engineering. The first semester course includes linear algebra and tensor analysis; analytic functions of a complex variable; integration in the complex plane; potential theory. The second semester course includes probability theory; eigenvalue problems; calculus of variations and extremum principles; wave propagation; other partial differential equations of evolution.
Spr ENGN2020 S01 24479 TTh 10:30-11:50(09) "To Be Arranged"
ENGN 2110. Business Engineering Fundamentals I.
The course examines core concepts in distinct areas through three modules: (1) intellectual property and business law, (2) technical marketing and (3) finance. All aspects of intellectual property will be treated, models on how to analyze markets will be discussed, culminating in a finance module which utilizes accounting fundamentals and models to perform financial analysis.

Fall ENGN2110 S01 14879 Th 3:00-5:50 (E. Suuberg)

ENGN 2120. Business Engineering Fundamentals II.
The course examines core concepts in distinct areas through three modules: (1) organizations, leadership, and human capital, (2) implementing radical technology change, and (3) engineering ethics. Organization, leadership and human capital focuses on the attributes of effective leadership and the tactical operation of start-up companies, implementing radical technological change centers on disruptive technologies and their adaptation in the marketplace, and ethics treats the issues that arise in small start-up organizations with an emphasis on the interface of ethics and environmental, health and safety issues.

Spr ENGN2120 S01 24480 W 3:00-5:50 (J. Harry)

ENGN 2130. Innovation and Technology Management I.
Examines core concepts through four modules: (1) Industry Dynamics of Technological Innovation, (2) Formulating Technological Innovation Strategy, (3) Implementing Technological Innovation Strategy, and (4) Early Commercialization and Deployment. Industry Dynamics of Innovation will explore some of the drivers of technology innovation. Implementing Technological Innovation Strategy explores execution issues concerning the flow of technology and innovation from concept to physical product or service. Early Commercialization and Deployment will focus on more salient strategic and operational issues related to commercial readiness and roll-out of a technology-based product or service. Emphasis will be on technology oriented entrepreneurial enterprises, but exploration will also include larger more established organizations.

Fall ENGN2130 S01 15532 T 3:00-5:50 (R. Petteruti)

ENGN 2140. Innovation and Technology Management II.
Explores concepts relevant to the management of operations in industrial enterprises with an emphasis on technology-oriented firms. Topics fall into three basic modules: (1) Capacity Planning, (2) Industrial Engineering, and (3) Materials & Resource Engineering. Capacity Planning will focus on capacity considerations in manufacturing and service organizations. Industrial Engineering will examine optimizing plant and process layouts. Materials & Resource Engineering will cover various aspects of planning and scheduling material, labor, and work center capacity. Inventory management techniques will also be introduced and examined as will concepts such as materials requirements planning and aggregate planning.

Spr ENGN2140 S01 24481 T 3:00-5:50 (R. Petteruti)

ENGN 2150. Technology Entrepreneurship and Commercialization I.
ENGN 2150 and the spring ENGN 2160 form a sequence that develops the skills for technology-based entrepreneurship. It teaches creation of viable high-growth-potential new ventures from emerging science and technology. It is from emerging S&T that a high percentage of new jobs are created, both by existing large companies and through the formation of new companies. You will examine S&T for new opportunities, create novel product or service concepts from these sources and determine whether these concepts truly represent new business opportunities. Pedagogy is a combination of lectures and "experiential learning", with work undertaken as a two-semester project. Enrollment limited to 30 graduate students in the IMEE program.

Fall ENGN2150 S01 15533 M 3:00-5:50 (A. Kingon)

ENGN 2160. Technology Entrepreneurship and Commercialization II.
ENGN 2160 and the prerequisite fall course 2150 form a course sequence that develops the knowledge of, and embeds the skills for, technology-based entrepreneurship. While 2150 has helped you to examine science and technology sources, and create a portfolio of opportunities from these, this course continues by developing selected opportunities into a compelling business case for the creation of a high growth potential new venture. Once again, learning is by a combination of lectures and "experiential learning", with work undertaken as a guided two-semester project. Prerequisite: ENGN 2150. Enrollment limited to 30 graduate students in the IMEE program.

Spr ENGN2160 S01 24482 M 3:00-5:50 (E. Suuberg)

ENGN 2180. Globalization Immersion Experience and Entrepreneurship Laboratory.
In this course, students will gain a better understanding of the political, social and cultural dynamics that influence entrepreneurial enterprises in different world regions. Meetings will be arranged with high technology companies and their venture arms, academic incubators, investment professionals, legal professionals, government officials, entrepreneurs, and other university faculty and students. The semester becomes a global entrepreneurship and innovation "laboratory" where students experience and take part in guest lectures from experts working in other countries. Classroom discussions, student presentations, papers and readings will be used to focus and further understand the globalization dynamic and its relationship to entrepreneurship. Prerequisite: ENGN 2110. Enrollment limited to graduate students in the PRIME program.

Spr ENGN2180 S01 24483 Th 3:00-5:50 (P. McHugh)

ENGN 2210. Continuum Mechanics.

Fall ENGN2210 S01 15534 MWF 12:00-12:50(12) (A. Bower)


Spr ENGN2220 S01 24484 MWF 10:00-10:50(03) (D. Henann)

ENGN 2240. Linear Elasticity.

Fall ENGN2240 S01 15535 MWF 11:00-11:50(02) (H. Gao)


ENGN 2270. Advanced Elasticity.

ENGN 2280. Topics in Continuum Mechanics.
Devoted to one or more advanced topics in continuum mechanics not covered in detail by the regular courses. Examples are: nonlinear viscoelastic constitutive equations, strain gradient and micropolar theories of elasticity, coupled mechanical and thermal or electromagnetic phenomena, and continuum thermodynamics.

Spr ENGN2280 S01 24486 Th 4:00-6:30(17) (P. Guduru)
ENGN 2420. Plasticity.
The theory of inelastic behavior of materials with negligible time effects. Experimental background for metals and fundamental postulates for plastic stress-strain relations. Variational principles for incremental elastic-plastic problems, uniqueness. Upper and lower bound theorems of limit analysis and shakedown. Slip line theory. Representative problems in structural analysis, metal forming, indentation, strain and stress concentrations at notches, and ductile failure.

ENGN 2320. Experimental Mechanics.
The design and evaluation of experiments in solid mechanics. Considers methods of experimental stress analysis and for the mechanical testing of materials. Topics covered include photoelasticity, creep and relaxation tests, high-speed testing, stress wave propagation, fatigue, and fracture. Techniques, instrumentation, and recording systems for the static and dynamic measurement of mechanical parameters such as forces, displacements, velocities, accelerations, and strains.

Continuum and atomistic descriptions of diffusion in solids. Techniques of stress analysis and shakedown. Incremental plasticity, plasticity, work-hardening, stress-corrosion, creep, fatigue, hardening mechanisms, etc.

The study and experimental analysis of solid structures from crystallography and crystal chemistry viewpoints. Electronic structure of the atom as related to core level chemical analysis techniques in material science. Atomic arrangements in solids, form crystallography, crystal symmetry and symmetry of finite objects, and experimental techniques in x-ray diffraction.

ENGN 2490B. To Be Determined.
ENGN 2500. Medical Image Analysis.
Explosive growth in medical image analysis has enabled noninvasive methods to diagnose and treat diseases. The course will first discuss the fundamentals of formation of medical images such as CT, MRI, ultrasound, and nuclear imaging; then consider clinical constraints and discuss methods in image guided therapy/surgery, techniques to detect, delineate, measure, and visualize medical organs and structures.

ENGN 2501. Digital Geometry Processing.
Three-dimensional geometric models are fundamental for applications in computer vision, computer graphics, medical imaging, computer aided design, visualization, multimedia, and many other related fields. This course includes the study of basic data structures and algorithms for representing, creating, manipulating, animating, editing, and analyzing digital geometry models, such as point clouds and polygon meshes, as well as state-of-the-art material from the current scientific literature. This is a project oriented course with several programming assignments and a final project. Students are expected to have successfully completed an introductory computer graphics/vision course or have an equivalent background. Instructor permission required. Open to seniors and graduate students.

ENGN 2520. 3D Photography.
Three-dimensional geometric models are fundamental for applications such as computer animation, game development, electronic commerce, heritage preservation, reverse engineering, and virtual reality. This course covers 3D capture techniques and systems, surface representations and data structures, as well as methods to smooth, denoise, edit, compress, transmit, simplify, and optimize very large polygonal models. Instructor permission required.

This course covers fundamental topics in pattern recognition and machine learning. We will consider applications in computer vision, signal processing, speech recognition and information retrieval. Topics include: decision theory, parametric and non-parametric learning, dimensionality reduction, graphical models, exact and approximate inference, semi-supervised learning, generalization bounds and support vector machines. Prerequisites: basic probability, linear algebra, calculus and some programming experience.

Fall ENGN2420 S01 15536 MW 9:00-9:50(2) (A. Van De Walle)
ENGN 2420. Kinetic Processes and Mechanisms in Materials Science.
Continuum and atomistic descriptions of diffusion in solids. Reactions involving surfaces and interfaces, including evaporation, adsorption, grain growth, and coarsening. Phase transformation kinetics, including nucleation, growth, solidification, spinodal decomposition, and martensitic transformations. Analysis of systems with multiple kinetic mechanisms (typical examples include oxidation, crystal growth, and sintering). Prerequisite: background in basic thermodynamics. Recommended: ENGN 1410 or 2410 or equivalent.

Fall ENGN2430 S01 15537 TTh 1:00-2:20(10) 'To Be Arranged'
ENGN 2440. Strength of Solids.
Mechanical behavior of solids as interpreted through atomistic mechanisms. Theory and characteristics of dislocations in continuous and crystalline media. Intrinsic and extrinsic stacking faults, extended dislocations, point defects, nodes and networks, disclinations, crystal boundaries. Applications of dislocation theory to single and polycrystalline plasticity, work-hardening, stress-corrosion, creep, fatigue, hardening mechanisms, etc.

Fall ENGN2490A S01 24487 TTh 2:30-3:50(11) (P. Felzenszwalb)
An introduction to the basics of linear, shift invariant systems and signals. Quantization and sampling issues are introduced. Discrete time and DFT properties, fast DFT algorithms, and spectral analysis are discussed. IIR and FIR digital filter design is a focus; stochastic and deterministic signals are introduced. MATLAB exercises are a significant part of the course.
Fall ENGN2530 S01 15540 MWF 11:00-11:50(02) (H. Silverman)

ENGN 2540. Speech Processing.
The basics for speech production and hearing are introduced. PDEs and simplified vocal-tract models are derived. LPC, DFT filterbank and time varying signal processing for speech recognition analysis are discussed in mathematical detail. Dynamic programming, vector quantization, hidden Markov modeling, and neural-network pattern recognition for speech are introduced. Offered every other year.

ENGN 2560. Computer Vision.
An interdisciplinary exploration of the fundamentals of engineering computer vision systems (e.g., medical imaging, satellite photo interpretation, industrial inspection, robotics, etc.). Classical machine vision paradigms in relation to perceptual theories, physiology of the visual context, and mathematical frameworks. Selections from Gestalt psychology, Gibsonian approach primate visual pathways, edge-detection, segmentation, orientation-selectivity, relaxation-labeling, shading, texture, stereo, shape, object-recognition.
Spr ENGN2560 S01 24488 TTh 1:00-2:20(10) (B. Kimia)

The study of stochastic processes and a number of applications central to electrical engineering. Analysis of continuous and discrete time Gaussian and second order stochastic processes. Stochastic calculus. Innovations and spectral representations. Markov random fields. Applications to Kalman filtering, the detection of signals in the presence of noise, and two-dimensional image processing. MATLAB projects. Prerequisite: an undergraduate level course in probability or statistics.

ENGN 2600. Electronic Processes in Semiconductors.
Electronic processes primarily in semiconductors with tetrahedral bonding (Si, Ge, GaAs compounds). Topics include phonon spectra, band structure, impurity states, electron and hole distributions, optical properties, electron plasma, scattering processes, excess and hot carriers, semiconductor-metal transitions, one-and two-dimensional electron gas, and amorphous semiconductors. Prerequisite: ENGN 1590 and Intro Quantum Mechanics or equivalent.

Current and proposed semiconductor devices: bipolar transistors (silicon and heterojunction); field effect transistors (MOSFETs, heterostructure, and submicron FETs); hot-electron and quantum-effect devices; and photonic devices (LEDs, semiconductor lasers, and photodetectors). Prerequisites: ENGN 1590 or equivalent introductory device course; some quantum mechanics helpful but not required.
Spr ENGN2610 S01 24489 MWF 12:00-12:50(05) (A. Zaslavsky)

ENGN 2620. Solid State Quantum and Optoelectronics.
Incorporates the study of interaction of radiation with matter emphasizing lasers, nonlinear optics, and semiconductor quantum electronics. Q-switching and mode-locking, electro- and acousto-optic interactions, harmonic generation and parametric processes, self-focusing and phase modulation, stimulated Raman and Brillouin scattering, ultrashort pulse generation, nonlinear processes of conduction electrons in semiconductors, bulk and surface polaritons. Prerequisite: ENGN 2620 or equivalent.
Fall ENGN2620 S01 15541 MWF 1:00-1:50(06) (A. Nummikko)

ENGN 2630. Electro-Optical Properties of Materials and Biomolecules.
Fundamental ideas and principles relevant to the understanding of the electrical and optical properties of materials and bio-molecules are emphasized. The mathematics is deliberately kept to a minimum. Topics include metals, semiconductors dielectric materials, magnetic materials, superconductors, carbon nanotubes, DNA, photosynthesis and redox proteins. Prerequisites: ENGN 0510 and PHYS 0470.

ENGN 2640. Classical Theoretical Physics II (PHYS 2040).
Interested students must register for PHYS 2040.

ENGN 2660. Physics and Technology of Semiconductor Heterostructures.
Covers, largely from an experimental point of view, topics of current interest in semiconductor heterostructure physics and technology; magnetotransport in two-dimensional electron gas; integer and fractional quantum Hall effects; resonant tunneling and superlattice transport; optical and transport properties of quantum wires and dots; heterostructure-based devices; other topics of student interest. Prerequisites: PHYS 1410 or equivalent quantum mechanics and ENGN 1590 or introductory device course helpful but not required.

ENGN 2730. Advanced Thermodynamics I.
Fundamental principles of macroscopic equilibrium; thermodynamic stability; Gibbs relations and chemical thermodynamics; applications to various systems, including fluids, solids, and magnetic and dielectric materials. Fundamental principles of macroscopic nonequilibrium thermodynamics (irreversible processes). Entropy production; Curie’s principle; Onsager-Casimir reciprocal relations; applications to transport and relaxation phenomena in continuous systems.

ENGN 2740. Advanced Thermodynamics II.
Introduction to the statistical mechanics of equilibrium phenomena for classical and quantum-mechanical systems. Ensemble theory; fluctuations; statistical interpretation of the laws of thermodynamics; applications to ideal gases, chemical equilibrium, simple crystals, magnetic and dielectric materials, radiation, and condensation phenomena.

ENGN 2750. Chemical Kinetics and Reactor Engineering.
This course focuses on the fundamentals of chemical kinetics with engineering applications. Topics include: quantum chemistry, statistical thermodynamics, and transition state theory; light versus loose transition states; the kinetics of gases, liquids, and surfaces; adsorption, desorption, surface diffusion; enzyme kinetics and biological processes; formation, solution, and interpretation of elementary mechanisms; global versus local sensitivity analysis; uncertainty quantification; and the coupling between fluid dynamics and chemical reactions.
Fall ENGN2750 S01 15622 MWF 12:00-12:50(12) (C. Goldsmith)
Spr ENGN2750 S01 24593 MWF 1:00-1:50(06) (C. Goldsmith)

ENGN 2760. Heat and Mass Transfer.
Spr ENGN2760 S01 24491 MWF 10:00-10:50(03) (J. Liu)

ENGN 2770. Atomistic Reaction Engineering.
Covers the principles of operation of heterogeneous catalysis and advanced reaction engineering with an emphasis on catalysis theory. Includes electronic structure calculations, linear scaling relations, free energy relations, surface reactivity, rate theory, and electrocatalytic concepts. Applications of study in this course will focus on catalysts for energy conversion. Students should have a background in chemical reactions and thermodynamics.

ENGN 2810. Fluid Mechanics I.
Formulation of the basic conservation laws for a viscous, heat conducting, compressible fluid. Molecular basis for thermodynamic and transport properties. Kinematics of vorticity and its transport and diffusion. Introduction to potential flow theory. Viscous flow theory: the application of dimensional analysis and scaling to obtain low and high Reynolds number limits.
Fall ENGN2810 S01 15613 MWF 2:00-2:50(07) (J. Franck)
ENGN 2910A. Advanced Computer Architecture.
This course focuses on advanced computer architecture concepts, including superscalar processor design, out-of-order execution, branch prediction, multi-core processors, memory hierarchy consistency, GPU architectures, and architecture of large-scale systems such as data centers and supercomputers. Class work expected to include HWs, Labs, and projects. Prerequisite: ENGN 1640 or permission of instructor.

ENGN 2910B. Advanced Process in Materials: Thin Film Processing and Characterization.
No description available.

ENGN 2910C. Advanced Processing of Materials.
This course will present a detailed consideration of processing of specific types of materials. In this particular offering, electronic materials will be the focus of the discussion. Detailed state of the art methods of processing will be described and the relationship between processing and the resulting properties will be discussed.

ENGN 2910D. Engineering and Design I.
No description available.

ENGN 2910E. Complex Fluids.
Complex fluids comprise a large class of "soft" microstructured materials which are encountered extensively in engineering applications and biological systems. This course will explore the interrelation between the microscopic physics, microstructure and macroscopic properties of complex fluids. Topics include surfactants and self-assembly, intermolecular forces and stability of colloidal suspensions, polymer solutions, ordered phases and liquid crystals, electrokinetic phenomena, rheology.

ENGN 2910F. Nano and Micro Mechanics of Solid Interfaces.
This course covers the topics: Mechanics of intermolecular forces and surface forces; Adhesion and friction of hydrophobic and hydrophilic surface complexes; Mechanics aspect of chemical etching and chemical reactions on solid surfaces; Interface energetics and kinetics with anisotropic elasticity and diffusion equations; Micromechanics of grain boundaries and interface fracture Nano and micro mechanics of single asperity and rough-surface contact friction.

ENGN 2910G. Topics in Translational Research and Technologies.
To improve human health, engineering and scientific discoveries must be explored in the context of application and translated into human/societal value. Translational research is creating a fundamental change in the way basic science and engineering research has operated for decades, breaking down the literal and figurative walls that separate basic scientists/engineers and clinical researchers. Such discoveries typically begin at "the bench" with basic research--and in the case of medicine--then progress to the clinical level, or the patient's "bedside." This seminar course will utilize case studies to demonstrate to students how the translational research unfolds. Lectures will be delivered by clinicians, medical researchers, engineers, and entrepreneurs, with case studies focused on topics ranging from value creation, IRB, HIPAA, FDA approval, etc.

ENGN 2910H. Flat Panel Display.
No description available.

ENGN 2910I. Mechanics of Entropic Forces in Biological Adhesion.
Course will cover fundamental concepts of entropic force and its significance in mechanical systems involving "soft matter". A prominent example is cell adhesion which plays a central role in cell migration, spreading, differentiation and growth. For such problems, the importance of mechanics and mechanical forces has been widely recognized and are currently under intensive research. This course is also aimed to stimulate live discussions on potential research topics and opportunities at the interface between solid mechanics and biological mechanics, with emphasis on cell-substrate, cell-cell and cell-particle interaction. Fundamental concepts to be discussed include Brownian motion, fluctuation, diffusion, dissipation, ligand-receptor bonds, single molecule mechanics, stochastic dynamics of binding/rebinding, elasticity, stress fibers, cytoskeleton, focal adhesion and endocytosis.

ENGN 2910J. Mechanics and Surface Science of Nanostructures.

Course is designed for students with a strong background that want to learn more about mathematical and mechanical descriptions of the cell and its functions. It will include an overview of cell biology emphasizing locomotion, mitosis (cell division), intracellular transport, cellular mechanotransduction, and biological material properties. The course will draw examples from recent theoretical and experimental research investigations, and teach quantitative tools commonly used by engineers in the field.

ENGN 2910L. Chemical and Transport Processes in the Environment.
This course will cover fundamental properties and processes that are important for the fate and transport of chemicals in the environment. Topics will include acid/base speciation, complexation, sorption, phase-partitioning, and solution chemistry. Emphasis will be placed on natural and engineered environmental systems, including a range of environmentally relevant media (e.g. water, air, soil/sediments, plants, organisms). Conceptual understanding of chemical structure and its role in environmental transport will be highlighted, while quantitative approaches will be used to solve problems.

ENGN 2910M. Biosensors and Applied Microfluidics.
This course will acquaint students with two modules: 1) new approaches to detection and quantification of biological molecules for diverse purposes ranging from medical diagnostics to food safety to defense, 2) processes at the microscale which can be translated into applications. The topics will include sensing platforms, devices, instrumentation, biomolecular engineering of probe molecules, quantitative evaluation, separations, sample stacking, DNA/protein sizing and diagnostic devices for use in developing countries. Lectures, assignments, a group design project and a laboratory will acquaint students with the state-of-the-art in biosensors and applied microfluidics. The course is relevant to physicists, chemists, biologists and engineers.

ENGN 2910N. Molecular and Cellular Biomechanics.
Mechanics and statistical mechanics applied to biological systems. Topics will include semiflexible polymers (DNA, microtubules, actin, flagella), membranes, and molecular motors. We will cover fundamentals including Brownian motion, random walks, diffusion, the fluctuation-dissipation theorem, and electrostatics of ions in solutions.
ENGN 2910Q. Atomistic Simulation in Mechanics and Physics
Random numbers in molecular simulations, Monte Carlo methods applied to equilibrium systems, Kinetic Monte Carlo methods, Molecular dynamics with simple potentials - equilibrium properties in various ensembles (ENV,NVT,NPT,NoT) and non-equilibrium properties. Simulations with three-body potentials and EAM potentials. Molecular statics. Introduction to quantum mechanical methods, Application to the above methods to defect interactions in solids, structure of surfaces, crystal growth and structure of nanostructures.

ENGN 2910P. Nano-system Design
The goal of this course is to provide a broad understanding of the many fields that are involved in electronic nanotechnology. The material will focus on considering how new basic devices intended to replace silicon-based transistors, such as single-molecule organic switches and nanotube electron conduits, will impact VLSI, computer architecture, and how we may design systems to take advantage of the opportunities they offer. Class will include a mix of lectures and discussion on assigned reading of recent publications. Students will be responsible for leading and participating in these discussions. A course project will also be required. Prerequisites: ENGN 1640 and 1600 are helpful, but not required.

ENGN 2910Q. Chemical Kinetics and Reactor Engineering
This course focuses on the fundamentals of chemical kinetics with engineering applications. Topics include: quantum chemistry, statistical thermodynamics, and transition state theory; tight versus loose transition states; the kinetics of gases, liquids, and surfaces; adsorption, desorption, surface diffusion; enzyme kinetics and biological processes; formation, solution, and interpretation of elementary mechanisms; global versus local sensitivity analysis; uncertainty quantification; and the coupling between fluid dynamics and chemical reactions.

ENGN 2910S. Cancer Nanotechnology
This course will integrate engineering and biomedical approaches to diagnosing and treating cancer, particularly using nanotechnology and BioMEMS. Topics will include the extracellular matrix and 3D cell culture, cancer cell invasion in microfluidic devices, heterotypic interactions, cancer stem cells and the epithelial-mesenchymal transition, angiogenesis and drug targeting, circulating tumor cells and biomarker detection, as well as molecular imaging and theranostics. Recommended coursework includes ENGN 1110 (Transport and Biotransport), ENGN 1210 (Biomechanics) and ENGN 1490 (Biomaterials) or equivalents.

ENGN 2910T. Physics of Materials
No description available.

ENGN 2910U. Quantum, Statistical and Continuum Mechanics
No description available.

ENGN 2910V. Simulation Methods in Physics and Mechanics
No description available.

ENGN 2910W. Synthesis of VLSI Systems
Promotes understanding of the algorithms used in designing many of today's CAD tools used for VLSI. Topics include synthesis of two-level and multi-level logic, logic testability and automatic test pattern generation, technology mapping, and sequential synthesis. Also introduces efficient manipulation algorithms for logic functions (based on Binary Decision Diagrams). Prerequisite: ENGN 1630. ENGN 1600 is helpful.

ENGN 2910X. Video Processing
This special topic course will address the rapidly evolving technologies involved in representing and processing video data, including compression, tracking and 3-D modeling. The course will involve projects to implement live and file-based video processing algorithms as well as periodic quizzes. Projects will be carried out primarily in C++.

ENGN 2910Z. Small Wonders: The Science, Technology, and Human Health Impacts of Nanomaterials
Survey course focusing on nanomaterials as enabling components in emerging nanotechnologies. Covers scaling laws for physicochemical properties, synthesis routes, manipulation and characterization tools, and example applications in sensors, composites, advanced energy devices, and nanomedicine. Impacts of nanomaterials on environment and health, including the interactions between nanoscale structures and biological molecules, cells, and whole organisms. Undergraduate enrollment by permission.

ENGN 2911A. Nanoelectronics
Review and analysis of novel and exotic electronic devices, and proposals for extending scaling into the nanometer regime. Contemporary research and development in areas such as nonclassical CMOS; single-electron and nanocrystal memories; 1D nanotube and nanowire transistors, qubits, quantum dots, spin transistors, molecular electronics; and the realization of such elements in arrays and biologically inspired networks.

ENGN 2911B. Electrical and Optical Properties of Materials and Biomolecules
Fundamental ideas and basic principles relevant to the understanding of the electrical and optical properties of solid-state materials and biomolecules are emphasized. Topics, including metals, semiconductors, dielectric materials, magnetic materials, superconductors, carbon nanotubes, DNA, and redox proteins, are selected in order to explain the operation of devices having current or future applications in engineering.

ENGN 2911C. Digital Integrated Circuit Testing and Hardware Security
Testing of digital integrated circuits has historically focused on the detection and diagnosis of manufacturing defects. However, in the past few years, testing for security has become an important hot topic. This class will cover testing fundamentals along with new approaches for the detection of hardware Trojans (malicious circuitry inserted into a design by an adversary). Related topics in hardware security and authentication, including physically unclonable functions, will also be discussed. Prerequisite: ENGN 1630 or equivalent or permission of instructor.

ENGN 2911D. Engineering and Design II
No description available.

ENGN 2911E. New Frontiers of Solid Mechanics in Nano- and Bio-Research
Course will cover fundamental concepts and methods in continuum, atomistic and statistical modeling of nanoscale and hierarchical materials in engineering and biology. Various systems and phenomena, including thin films, nanocrystalline materials, fracture, hierarchical tissue structures of bone and gecko, cell adhesion and endocytosis, carbon nanotubes and biomolecular assembly, are selected to stimulate discussions at the forefront of solid mechanics research.

ENGN 2911F. Topics in Emerging and Breakthrough Technologies
No description available.

ENGN 2911G. Physical Design of Digital Integrated Circuits
This class investigates the physical principles and algorithmic methodologies that are used in physically designing and implementing state-of-the-art digital circuits and high-performance processors. We'll also survey the main available design implementation tools in the market and examine new directions for innovative solutions.

ENGN 2911H. Computer Architecture
No description available.

ENGN 2911J. Computational Electromagnetics
This course will introduce numerical techniques for solving practical and theoretical problems in optical science. Using MatLab and Mathematica, students will develop a toolkit for physical optics and build an intuition for wave propagation (e.g. transfer matrices), Fourier optics (beam propagation methods, normal mode analysis), light emission/absorption (surface- and cavity-enhanced lifetimes) as well as general finite difference schemes (frequency and time domain). Prerequisites: ENGN 0510 or PHYS 0470; APMA 0330 or APMA 0350; MATH 0520 or MATH 0540; or equivalent courses.
ENGN 2911K. Biological Impacts of Nanomaterials. This course will emphasize advancements nanomaterials have made in several fields. In doing so, this course will cover fundamentals of nanomaterial synthesis and biological responses of nanomaterials if ingested, inhaled, or implanted. Biological concepts (immune response, cellular toxicity, etc.) will be combined with engineering concepts (manufacturing and property control) to understand the relationship between manufacturing and biological impacts of nanomaterials.

ENGN 2911L. Environmental Technologies and Human Health. No description available.

ENGN 2911X. Reconfigurable Computing. Driven by recent innovations in Field-Programmable Gate Arrays (FPGAs), reconfigurable computing offers unique ways to accelerate key algorithms. FPGAs offer a programmable logic fabric that provides the necessary hardware and communication assets to exploit parallelism opportunities arising in various algorithms. By mapping algorithms directly into programmable logic, FPGAs accelerators can deliver 10X-100X performance increases over generic processors for a large range of application domains. The class will describe FPGA architectures, reconfigurable systems, languages (SystemC) and design tools. The class will show a class of algorithmic techniques (e.g., dynamic programming) that are particularly attractive targets for reconfigurable computing. Mapping specific algorithms from different domains will also be described. These include computer vision, image and signal processing, network security, and bioinformatics algorithms. The class requires basic hardware and programming languages knowledge.

ENGN 2911Y. Verification, Test, Synthesis. This course will provide an overview of algorithms and techniques in electronic design automation relating to the synthesis, verification, and test of digital integrated circuits. Some topics covered will include synthesis of two-level and multi-level circuits, logic minimization, representations of combinational and sequential circuits for design automation, ordered binary decision diagrams, equivalence checking, verification coverage, assertions, and automatic test pattern generation. Classic techniques and recent state-of-the-art research advances will be both discussed.

ENGN 2911Z. Principles of Nano-Optics. The goal of this course is to help students build an intuition for light-matter interactions at the nanoscale, especially when optically active elements are located near complex surfaces. The course will begin with a review of the theoretical foundations of macroscopic electrodynamics, but will continue on to discuss specific experimental techniques for investigating microscopic behavior. Topics will include near-field optical microscopy, quantum dots and single molecule spectroscopy, surface plasmon polaritons, local density of states, and photonic crystals.

ENGN 2912A. Toxicity of Nanoparticles. This course will emphasize advancements nanoparticles have made in several medical fields such as preventing, diagnosing, and treating various diseases. This course will integrate fundamental knowledge of toxicity into such applications. In particular, the course will cover current results in terms of nanoparticle applications and potential toxicity. Toxicity in such organs as the lungs, blood, kidneys, liver etc. will be emphasized. Biological concepts will be combined with engineering concepts to understand the relationship between manufacturing and nanoparticle toxicity.

ENGN 2912B. Scientific Programming in C++. Introduction to the C++ language with examples from topics in numerical analysis, differential equations and finite elements. As a prerequisite, some programming knowledge, e.g., MATLAB projects. The course will cover the main C++ elements: data types; pointers; references; conditional expressions; streams; templates; Standard Template Library(STL); design and debugging techniques.

ENGN 2912C. Future Directions in Computing: From Bio and Quantum to Nano and 3D. Silicon-based electronics is the foundation of computing devices. The computer industry is reaching an important milestone, where physical limits arising from using optical lithography manufacturing techniques can stop the evolution of computational power as predicted by Moore's law. In this class, we explore some of the alternatives that can be used for future computing devices. Topics covered include: quantum computing, bio-based computing, spin-based computing, nanotube-based computing, computing with light and 3D chips.

ENGN 2912D. Networks and Network-on-Chip Design. Network-on-Chip communication fabrics are a very recent approach to multi-core system-on-chip design. This class will cover state-of-the-art research in the design and test of network-on-chip communication hardware and will compare these on-chip communication networks to more traditional networks. Additional aspects of system-on-chip design and test will also be explored. Prerequisites: ENGN 1630 and ENGN 1640 or equivalent experience in digital design.

ENGN 2912E. Low Power VLSI System Design. This course deals with the design of digital systems for low power dissipation. Issues that will be addressed include CMOS power dissipation, analysis and design tools used for lower power digital circuits, design methodologies for low power CMOS circuits, low power architecture designs, and a discussion on future challenges in low power digital design. Prerequisites: familiarity with basic MOSFET structure and computer architecture principles; some circuit analysis helpful.

ENGN 2912F. Soft Matter. This course is a special topics graduate course on soft matter, treating polymers, liquid crystals, surfactants, and colloids. The different topics will be unified by a common approach using statistical mechanics.

ENGN 2912G. Selected Topics in Physics of Locomotion (PHYS 2610E). Interested students must register for PHYS 2610E.

ENGN 2912H. Interfacial Phenomena. This course is an introduction to mechanics of material interfaces. Particular cases considered are liquid surfaces (surface tension, contact line slip, electro-wetting, etc), lipid membranes, and thin elastic plates and shells. The course will cover detailed analyses of statics and dynamics of these interface. Classical and modern research papers related to these topics will form the motivation for the discussion. A unified treatment of these apparently disparate interfaces is presented to conclude the course. Prerequisites: ENGN 2010, 2020, 2210, or 2810.

ENGN 2912I. Asymptotic and Perturbation Methods. In this introductory course to perturbation methods, topics covered are inspired by problems in solid mechanics (e.g. ridges and kinks in thin plates), fluid mechanics (e.g. viscous boundary layers), electrical circuits (van der Pol oscillator), and include regular and singular perturbations, methods of strained coordinates, multiple scales, averaging, WKB, Laplace's method and the method of steepest descent for approximating integrals, and solutions of partial differential equations. Prerequisite: ENGN 2010 and 2020.

ENGN 2912J. Asymptotic and Perturbation Methods. In this introductory course to perturbation methods, topics covered are inspired by problems in solid mechanics (e.g. ridges and kinks in thin plates), fluid mechanics (e.g. viscous boundary layers), electrical circuits (van der Pol oscillator), and include regular and singular perturbations, methods of strained coordinates, multiple scales, averaging, WKB, Laplace's method and the method of steepest descent for approximating integrals, and solutions of partial differential equations. Prerequisite: ENGN 2010 and 2020.

ENGN 2912K. Mixed-Signal Electronic Design. ADCs, DACs, switched-capacitor circuits, noise and distortion. Circuit simulation and system design projects. Examples will be used from various biological sensing and instrumentation applications and recent scientific literature. Prerequisite: ENGN 1620 and 1630, or instructor permission. Enrollment limited to 20.

ENGN 2912L. Topics in Bioelectronics. Seminar course covering subjects related to interactions between electronic and biological systems. Material includes energy harvesting, low-power electronic circuit design, biosensors and signal integrity, neuromorphic hardware, low-power wireless communications, and electrochemical methods. Emphasis on critical reading, technical analysis, presentation, and discussion. Design project.

Fall ENGN2912E S01 15614  TTh 10:30-11:50(13) 'To Be Arranged'

Fall ENGN2912F S01 15615  TTh 9:00-10:20(08) (T. Powers)

Fall ENGN2912G S01 15621  M 3:00-5:30(15) (S. Mandre)

Fall ENGN2912H S01 15621  M 3:00-5:30(15) (S. Mandre)

Fall ENGN2912I S01 15615  TTh 9:00-10:20(08) (T. Powers)

Fall ENGN2912J S01 15621  M 3:00-5:30(15) (S. Mandre)
ENGN 2920P. Topics in Optimization.
This course will cover various topics in discrete and continuous optimization. Topics include graph algorithms, dynamic programming, linear programming, convex optimization and coarse-to-fine methods. Prerequisites: basic theory of algorithms (at the level of an undergraduate algorithms course) and linear algebra.

ENGN 2921Q. Coherence of Light in Nanooptics and Plasmonics.
This class is a special topics graduate course focusing on advanced concepts in optics, including spatial and temporal coherence of optical fields, higher-order coherence phenomena in space-time domain, coherence effects at the nano- and micro-scale, optical and plasmonic interferometry using partially coherent sources. The subject is aimed at graduate and undergraduate students interested in optical communications, propagation of laser beams in biological or turbulent media, optical microscopy and imaging, as well as medical diagnostics. The concepts of "flipped teaching" and "learning by teaching" will be explored. Knowledge of advanced electricity and magnetism concepts is required.

ENGN 2921R. Implantable Devices.
This course will expose students to topics across the electrical and biological sciences through lecture, design, and laboratory exercises. Students will learn basic governing concepts of implantable device design, including those of tissue interfaces, power delivery, data transmission, hermetic packaging and biocompatibility, and in vivo evaluation through appropriate animal models including design of surgical approach. Teams will be formed early in the course and maintained throughout the semester. Successful teams will invent, design, build, and implant their unique device. Teams will have access and exposure to the Technology Ventures Office through guest lectures and individual meetings.

ENGN 2921Z. Application of Machine Learning to Experimental Science.
The course is designed to help introduce experimentalists (in engineering and related sciences) to the growing array of computational tools for data analysis. Using MatLab and Python, students will learn how to leverage dedicated software for numerical optimization (e.g. CVX and MOSEK) and machine learning (e.g. TensorFlow). Emphasis will be on exposure to different techniques and practical implementation, rather than underlying fundamentals. (Students seeking rigorous foundation in machine learning should see CSC1420/ENGN2520.) Initial assignments will introduce range of supervised and unsupervised machine learning approaches; final projects will provide students with opportunity to apply these methods to their own research data.

ENGN 2920A. Complex Fluids: Particles and Interfaces.
Introduces disperse systems (colloidal suspensions, emulsions, surfactant solutions, blood) with special attention to the thermodynamics and mechanics of interfaces. The course will bridge the physico-chemical and mechanical perspectives in the study of these materials. The intended audience is graduate students in Engineering, Physics, Chemistry, and Applied Mathematics. Prerequisite: We will sometimes use material from ENGN 2010/2020, such as differential equations, Fourier and Laplace transforms, elementary differential geometry, basic probability, vector calculus. Knowledge of basic solid/fluid mechanics will be helpful.

This course introduces the students to the mechanics aspects of battery materials and some of the current research problems. It will consist of a series of lectures by experts from academia and industry, which will cover the state of the art in lithium ion batteries, the role of mechanics in advancing the field, experimental studies, continuum modeling, ab initio modeling and practical design issues. There will be approximately one lecture each week (150 min); each lecture will focus on a specific aspect of battery materials, giving an in-depth treatment of scientific problems, the current state of understanding and future challenges.

ENGN 2920D. Environmental Technologies and Human Health.
This course explores interdisciplinary approaches to environmental safety and health drawing from Brown University faculty and other affiliated experts. Topics include history of environmental regulation and waste management; origin and chemistry of pollutants; biological impacts of exposure and risk assessment; pollutant dispersion, transport and bioaccumulation; and remediation technologies. Emphasis is placed on how scientific research impacts regulatory and engineering decisions regarding cleanup and management of contaminated sites. The target audience is graduate students and advanced undergraduates (permission required) with prior coursework or research in engineering, biology, or environmental studies. Enrollment limited to 30.

Fall ENGN2920D S01 15623 M 3:00-5:30(15) (R. Hurt)

This class describes the fundamentals of statistical mechanics with a focus on both traditional analytic methods and modern atomistic simulations methods. The class is divided in two parts. (i) Techniques used to calculate interactions at the atomic level are first covered, from simple interatomic potentials to quantum mechanical first-principles methods. (ii) Simulations techniques to sample atomic degrees of freedom for obtaining macroscopic quantities are then discussed, such as Monte Carlo and Molecular Dynamics. The tools presented in class are illustrated with ongoing examples that illustrate how these methods work in concert. Enrollment limited to 40 graduate students.

ENGN 2970. Preliminary Examination Preparation.
For graduate students who have met the tuition requirement and are paying the registration fee to continue active enrollment while preparing for a preliminary examination.
Fall ENGN2970 S01 14730 Arranged "To Be Arranged"
Spr ENGN2970 S01 23824 Arranged "To Be Arranged"

ENGN 2980. Special Projects, Reading, Research and Design.
Section numbers vary by instructor. Please check Banner for the correct section number and CRN to use when registering for this course.

ENGN 2990. Thesis Preparation.
For graduate students who have met the tuition requirement and are paying the registration fee to continue active enrollment while preparing a thesis.
Fall ENGN2990 S01 14731 Arranged "To Be Arranged"
Spr ENGN2990 S01 23825 Arranged "To Be Arranged"

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