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.), 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 eight Bachelor of Science (Sc.B.) degree programs. Of these, the Sc.B. programs in biomedical, chemical, computer, electrical, materials, and mechanical engineering are accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org/). The Sc.B. degree program in environmental engineering is not currently accredited by the Engineering Accreditation Commission of ABET, but will seek accreditation during the 2020-21 academic year. The engineering physics program is also offered, but is not accredited by ABET. 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 who would prefer a more introductory level calculus course may start in MATH 0100 and take MATH 0200 or MATH 0180 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 determined 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

A student may petition the Concentration Adviser 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 accreditation requirements. If the substitution involves taking an equal or higher level course in substantially the same area, whether at Brown or elsewhere, it can be approved by the Concentration Adviser. (For courses taken elsewhere, the credit must be officially transferred.) Students wishing to make substitutions of a broader nature should consult their Concentration Adviser for assistance with drafting their petition to the Engineering Concentration Committee, which may be approved by a majority vote.

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 or independent study 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.
The A.B. program also requires preparation in Mathematics equivalent to MATH 0300 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 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.

Special Concentrations

In addition to the standard programs described above, students may also petition the Engineering Concentration Committee to pursue a special engineering Sc.B. degree of their own design. Such special Sc.B. programs are not ABET-accredited. Students with a special concentration will receive an Sc.B. degree in engineering, but a specific area of specialization will not be noted on their transcript. A special Sc.B. concentration is intended to prepare graduates for advanced study in engineering or for professional practice, but in an area that is not covered by one of the existing Sc.B. programs. Accordingly, special concentration programs are expected to consist of a coherent set of courses with breadth, depth and rigor comparable to an accredited degree. A total of 21 engineering, mathematics, and basic science courses are required.

The program must include at least 3 courses in mathematics, at least 2 courses in physical or life sciences; and at least 12 courses in engineering. At least five of the engineering courses must be upper level courses, and one must be a capstone design course or independent study, which must be advised or co-advised by a member of the regular engineering faculty. Note that not all engineering courses may be used to meet Sc.B. requirements: for example, the courses not allowed to count toward the A.B., will not qualify. Petitions should be prepared in consultation with an engineering faculty adviser, who will submit the petition to the Engineering Concentration Committee. Petitions must include: (i) a statement of the objectives of the degree program, and an explanation of how the courses in the program meet these objectives; (ii) course descriptions for any courses in the program that are not part of standard ScB engineering concentrations; (iii) a detailed description of any independent study courses used for concentration credit, signed by the faculty adviser for this course; and (iv) an up-to-date internal transcript.

Professional Tracks

While we do not give course credit for internships, we officially recognize their importance via the optional Professional Tracks. The requirements for the professional tracks include all those of the standard tracks, as well as the following: Students must complete two full-time professional experiences, lasting two to four months each (or two part-time experiences of equivalent total effort), doing work that is related to their concentration programs. Such work is normally done within an industrial organization, but may also be done at a university under the supervision of a faculty member. For the work to be considered related to a concentration program, the job responsibilities must make use of the material from one or more courses of the concentration (regardless of whether the student has taken those courses or not at the time of the internship). On completion of each professional experience, the student must write and upload to ASK a reflective essay about the experience addressing the following prompts:

- Describe the organization you worked in and the nature of your responsibilities.
- Which courses were put to use in your work? Which topics, in particular, were important?
- In retrospect, which courses should you have taken before embarking on your work experience?
- What are the topics from these courses that would have helped you if you had been more familiar with them?
- What topics would have been helpful in preparation for this work experience that you did not learn at Brown?
- What did you learn from the experience that probably could not have been picked up from course work?
- Is the sort of work you did something you would like to continue doing once you graduate? Explain.
- Would you recommend your work experience to other Brown students? Explain.

The reflective essays are subject to the approval of the student’s concentration adviser.

Entry to the Professional Track requires a simple application form to be completed by the student and approved by the Concentration Advisor at the time of the concentration declaration. If the student has not yet declared a concentration, the form may be approved by the Chair of the Concentration Committee. The Concentration Advisor will certify that all Professional Track students have completed the necessary internships and will grant approval for the associated reflective essays. All other requirements remain identical to those in the standard tracks in the concentrations.

Chemical Engineering Track:

The Chemical Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org (http://www.abet.org). The education objectives of the Chemical 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 engineering or related fields; or to successfully pursue other careers that benefit from the analytical or quantitative skills acquired through the Brown ChE Program; (2) to effectively apply the principles of chemical 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 (1)-(7) 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>or ENGN 0031</td>
<td>Honors 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>
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</table>
## 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 (1) - (7) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at 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.

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<td>ENGN 0510</td>
<td>Electricity and Magnetism</td>
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</tr>
<tr>
<td>ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
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<tr>
<td>APMA 1650</td>
<td>Statistical Inference I</td>
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<tr>
<td>or APMA 1655</td>
<td>Statistical Inference I</td>
<td>1</td>
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<tr>
<td>or CSCI 1450</td>
<td>Probability for Computing and Data Analysis</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Advanced Placement Calculus (Physics/ Engineering)</td>
<td>1</td>
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<tr>
<td>or MATH 0170</td>
<td>Advanced Placement Calculus</td>
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<tr>
<td>MATH 0200</td>
<td>Intermediate Calculus (Physics/ Engineering)</td>
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<tr>
<td>or MATH 0180</td>
<td>Intermediate Calculus</td>
<td>1</td>
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<tr>
<td>or MATH 0350</td>
<td>Honors Calculus</td>
<td>1</td>
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<tr>
<td>APMA 0330</td>
<td>Methods of Applied Mathematics I, II</td>
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<tr>
<td>or APMA 0350</td>
<td>Applied Ordinary Differential Equations</td>
<td>1</td>
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<tr>
<td>APMA 0340</td>
<td>Methods of Applied Mathematics I, II</td>
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<tr>
<td>or APMA 0360</td>
<td>Applied Partial Differential Equations I</td>
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### 2. Upper-Level Chemical & Biochemical Engineering Curriculum

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
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<tbody>
<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0410</td>
<td>Materials Science</td>
<td>1</td>
</tr>
<tr>
<td>or NEUR 0010</td>
<td>The Brain: An Introduction to Neuroscience</td>
<td>1</td>
</tr>
</tbody>
</table>

Select one of the following series (other CSCI courses subject to approval):

- CSCI 0150 & CSCI 0160
- CSCI 0170 & CSCI 0180
- CSCI 0190

One advanced Computer Engineering foundations course:

- ENGN 1570 Linear System Analysis
- ENGN 1630 Digital Electronics Systems Design
- ENGN 1640 Design of Computing Systems
- MATH 0520 Linear Algebra
- or MATH 0540 Honors Linear Algebra

One advanced Computer Science course with significant programming:

- CSCI 0330 Introduction to Computer Systems
- or CSCI 0320 Introduction to Software Engineering
- or CSCI 1230 Introduction to Computer Graphics
- or CSCI 1380 Distributed Computer Systems
- or CSCI 1670 Operating Systems
- or CSCI 1680 Computer Networks

Select three upper-level electives from the list below (other ENGN or CSCI courses subject to approval). At least one must be an ENGN course and at least one must be a CSCI course.

1. BIOL 0200 The Foundation of Living Systems
2. CHEM 0330 Equilibrium, Rate, and Structure
3. MATH 0170 Advanced Placement Calculus
4. MATH 0190 Intermediate Calculus (Physics/ Engineering)
5. MATH 0200 Intermediate Calculus (Physics/ Engineering)
6. MATH 0350 Honors Calculus
7. APMA 0330 Methods of Applied Mathematics I, II
8. APMA 0350 Applied Ordinary Differential Equations
9. APMA 0340 Methods of Applied Mathematics I, II
10. APMA 0360 Applied Partial Differential Equations I
11. CHEM 0330 Equilibrium, Rate, and Structure
12. MATH 0190 Advanced Placement Calculus (Physics/ Engineering)
13. MATH 0200 Intermediate Calculus (Physics/ Engineering)
14. MATH 0350 Honors Calculus
15. APMA 0330 Methods of Applied Mathematics I, II
16. APMA 0350 Applied Ordinary Differential Equations
17. APMA 0340 Methods of Applied Mathematics I, II
18. APMA 0360 Applied Partial Differential Equations I
19. CHEM 0330 Equilibrium, Rate, and Structure
20. MATH 0190 Advanced Placement Calculus (Physics/ Engineering)
21. MATH 0200 Intermediate Calculus (Physics/ Engineering)
22. MATH 0350 Honors Calculus
23. APMA 0330 Methods of Applied Mathematics I, II
24. APMA 0350 Applied Ordinary Differential Equations
25. APMA 0340 Methods of Applied Mathematics I, II
26. APMA 0360 Applied Partial Differential Equations I
27. CHEM 0330 Equilibrium, Rate, and Structure
28. MATH 0190 Advanced Placement Calculus (Physics/ Engineering)
29. MATH 0200 Intermediate Calculus (Physics/ Engineering)
30. MATH 0350 Honors Calculus
31. APMA 0330 Methods of Applied Mathematics I, II
32. APMA 0350 Applied Ordinary Differential Equations
33. APMA 0340 Methods of Applied Mathematics I, II
34. APMA 0360 Applied Partial Differential Equations I
35. CHEM 0330 Equilibrium, Rate, and Structure
36. MATH 0190 Advanced Placement Calculus (Physics/ Engineering)
37. MATH 0200 Intermediate Calculus (Physics/ Engineering)
38. MATH 0350 Honors Calculus
39. APMA 0330 Methods of Applied Mathematics I, II
40. APMA 0350 Applied Ordinary Differential Equations
41. APMA 0340 Methods of Applied Mathematics I, II
42. APMA 0360 Applied Partial Differential Equations I
43. CHEM 0330 Equilibrium, Rate, and Structure
44. MATH 0190 Advanced Placement Calculus (Physics/ Engineering)
45. MATH 0200 Intermediate Calculus (Physics/ Engineering)
46. MATH 0350 Honors Calculus
47. APMA 0330 Methods of Applied Mathematics I, II
48. APMA 0350 Applied Ordinary Differential Equations
49. APMA 0340 Methods of Applied Mathematics I, II
50. APMA 0360 Applied Partial Differential Equations I
51. CHEM 0330 Equilibrium, Rate, and Structure
ENGN 1590  Introduction to Semiconductors and Semiconductor Electronics
ENGN 1600  Design and Implementation of Digital Integrated Circuits
ENGN 1610  Image Understanding
ENGN 1620  Analysis and Design of Electronic Circuits
ENGN 1680  Design and Fabrication of Semiconductor Devices
ENGN 1690  Photonics Devices and Sensors
ENGN 1930B  Biomedical Optics
ENGN 1931A  Photovoltaics Engineering
ENGN 1931F  Introduction to Power Engineering
ENGN 1931I  Design of Robotic Systems
ENGN 1931Y  Control Systems Engineering
ENGN 1931Z  Interfaces, Information and Automation
ENGN 2520  Pattern Recognition and Machine Learning
ENGN 2530  Digital Signal Processing
ENGN 2560  Computer Vision
ENGN 2610  Physics of Solid State Devices
ENGN 2620  Solid State Quantum and Optoelectronics
ENGN 2910A  Advanced Computer Architecture
ENGN 2911X  Reconfigurable Computing for Machine/Deep Learning
ENGN 2912B  Scientific Programming in C++
ENGN 2912E  Low Power VLSI System Design
CSCI 0320  Introduction to Software Engineering
CSCI 1230  Introduction to Computer Graphics
CSCI 1270  Database Management Systems
CSCI 1300  User Interfaces and User Experience
CSCI 1320  Creating Modern Web & Mobile Applications
CSCI 1380  Distributed Computer Systems
CSCI 1410  Artificial Intelligence
CSCI 1480  Building Intelligent Robots
CSCI 1570  Design and Analysis of Algorithms
CSCI 1600  Real-Time and Embedded Software
CSCI 1660  Introduction to Computer Systems Security
CSCI 1670  Operating Systems
CSCI 1680  Computer Networks
CSCI 1730  Design and Implementation of Programming Languages
CSCI 1760  Multiprocessor Synchronization
CSCI 1900  csciStartup

3. Capstone Design

ENGN 1650  Embedded Microprocessor Design
or ENGN 1000  Projects in Engineering Design I
or ENGN 1001  Projects in Engineering Design II

4. General Education Requirement: At least four approved courses must be taken in humanities and social sciences

Total Credits 21

1 Or Biology course beyond BIOL 0200 subject to Concentration Advisor approval

2 Subject to approval by the concentration advisor, the third upper-level elective may optionally be chosen from another department such as CLPS, NEUR, PHYS, or CHEM if it has a significant quantitative physical science emphasis.

3 Subject to approval by the concentration advisor, an independent study course (ENGN 1970/ENGN 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.

Electrical Engineering Track:

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 (1) - (7) 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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<tr>
<td>ENGN 0720</td>
<td>Thermodynamics</td>
</tr>
<tr>
<td>ENGN 0310</td>
<td>Mechanics of Solids and Structures</td>
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<tr>
<td>or ENGN 0810</td>
<td>Fluid Mechanics</td>
</tr>
<tr>
<td>or CSCI 0160</td>
<td>Introduction to Algorithms and Data Structures</td>
</tr>
<tr>
<td>or CSCI 0180</td>
<td>Computer Science: An Integrated Introduction</td>
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<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
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<tr>
<td>MATH 0190</td>
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<td>or APMA 1650</td>
<td>Statistical Inference I</td>
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<tr>
<td>or APMA 1710</td>
<td>Information Theory</td>
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<tr>
<td>or MATH 0520</td>
<td>Linear Algebra</td>
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<td>or MATH 0540</td>
<td>Honors Linear Algebra</td>
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<tr>
<td>CSCI 0150</td>
<td>Introduction to Object-Oriented Programming and Computer Science</td>
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<td>or CSCI 0040</td>
<td>Introduction to Scientific Computing and Problem Solving</td>
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<td>or CSCI 0111</td>
<td>Computing Foundations: Data</td>
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<td>or CSCI 0170</td>
<td>Computer Science: An Integrated Introduction</td>
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<td>or CSCI 0190</td>
<td>Accelerated Introduction to Computer Science</td>
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<td>Introduction to Scientific Computing</td>
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<td>or ENGN 1931Z</td>
<td>Interfaces, Information and Automation</td>
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2. Upper-Level Electrical Engineering Curriculum

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<th>Course</th>
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<tbody>
<tr>
<td>ENGN 1570</td>
<td>Linear System Analysis</td>
</tr>
<tr>
<td>ENGN 1620</td>
<td>Analysis and Design of Electronic Circuits</td>
</tr>
<tr>
<td>ENGN 1630</td>
<td>Digital Electronics Systems Design</td>
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</table>
Since then, environmental science, engineering, and technology have become essential components of the School of Engineering. The program will seek accreditation from the Engineering Accreditation Commission of ABET during Brown's upcoming review period in 2020-2021 when the rest of the School of Engineering's existing accredited programs will be reviewed.

The education objectives of the program are: (1) to prepare students to pursue scientific or technical careers, starting with entry-level positions in industry, or in graduate study in environmental engineering; (2) to develop critical thinking and problem-solving skills that yield sustainable solutions to complex environmental problems for the protection of human health and the environment. The student outcomes of this program are intended to be those enumerated in items (1) - (7) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

### 3. Environmental Engineering Specialization - Complete at least three courses from the following groups:

#### At least one advanced Electrical Engineering foundations course:
- ENGN 1230 Instrumentation Design
- ENGN 1580 Communication Systems
- ENGN 1590 Introduction to Semiconductors and Semiconductor Electronics
- ENGN 1600 Design and Implementation of Digital Integrated Circuits
- ENGN 1610 Image Understanding
- ENGN 1640 Design of Computing Systems

#### Up to two other Electrical Engineering Courses
- ENGN 1220 Neuroengineering
- ENGN 1660 Optics
- ENGN 1650 Embedded Microprocessor Design
- ENGN 1680 Design and Fabrication of Semiconductor Devices
- ENGN 1690 Photonics Devices and Sensors
- ENGN 1930B Biomedical Optics
- ENGN 1931A Photovoltaics Engineering
- ENGN 1931F Introduction to Power Engineering
- ENGN 1931I Design of Robotic Systems
- ENGN 1931Y Control Systems Engineering
- ENGN 1931Z Interfaces, Information and Automation

#### Up to one interdisciplinary engineering science course:
- CLPS 1491 Neural Modeling Laboratory
- CLPS 1520 Computational Vision
- CSCI 0330 Introduction to Computer Systems
- ENGN 1370 Advanced Engineering Mechanics
- ENGN 1450 Properties and Processing of Electronic Materials
- NEUR 2110 Statistical Neuroscience
- PHYS 1420 Quantum Mechanics B

### 4. Capstone Design: At least one course from the following:
- ENGN 1650 Embedded Microprocessor Design
- or ENGN 1000 Projects in Engineering Design I
- or ENGN 1001 Projects in Engineering Design II

### 5. General Education Requirement: At least four approved courses must be taken in humanities and social sciences

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1931Z</td>
<td>Interfaces, Information and Automation</td>
<td>1</td>
</tr>
<tr>
<td>CSCI 0330</td>
<td>Introduction to Computer Systems</td>
<td>3</td>
</tr>
<tr>
<td>ENGN 1370</td>
<td>Advanced Engineering Mechanics</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1450</td>
<td>Properties and Processing of Electronic Materials</td>
<td>1</td>
</tr>
<tr>
<td>NEUR 2110</td>
<td>Statistical Neuroscience</td>
<td>1</td>
</tr>
<tr>
<td>PHYS 1420</td>
<td>Quantum Mechanics B</td>
<td>1</td>
</tr>
</tbody>
</table>

Total Credits: 21

---

**Environmental Engineering Track:**

Brown's Environmental Engineering program was launched in 2013. The first graduates completed the program with the Sc.B. degree in Environmental Engineering in Spring 2017. The program has graduated Sc.B. degree recipients every year since then. The program will seek accreditation from the Engineering Accreditation Commission of ABET during Brown's upcoming review period in 2020-2021 when the rest of the School of Engineering's existing accredited programs will be reviewed.

The education objectives of the program are: (1) to prepare students to pursue scientific or technical careers, starting with entry-level positions in industry, or in graduate study in environmental engineering; (2) to develop critical thinking and problem-solving skills that yield sustainable solutions to complex environmental problems for the protection of human health and the environment. The student outcomes of this program are intended to be those enumerated in items (1) - (7) Student Outcomes as defined by the "ABET Criteria for Accrediting Engineering Programs" (available online at http://www.abet.org/accreditation-criteria-policies-documents/).

### 3. Upper-Level Environmental Engineering Curriculum (5 Credits)

- ENGN 1340 Water Supply and Treatment Systems - Technology and Sustainability
- ENGN 1931P Energy and the Environment

Three advanced Engineering courses from the list below:

- ENGN 1110 Transport and Biophysics Processes
- ENGN 1120 Reaction Kinetics and Reactor Design
- ENGN 1130 Chemical Engineering Thermodynamics
- ENGN 1710 Heat and Mass Transfer
- ENGN 1860 Advanced Fluid Mechanics
- ENGN 1930U Renewable Energy Technologies
- ENGN 1931A Photovoltaics Engineering
- ENGN 1931F Introduction to Power Engineering
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, from start-ups to multinational corporations, 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 (1) - (7) 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 Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1931R</td>
<td>The Chemistry of Environmental Pollution</td>
<td></td>
</tr>
<tr>
<td>ENGN 2911P</td>
<td>Fate and Transport of Environmental Contaminants</td>
<td></td>
</tr>
</tbody>
</table>

2. Capstone Design

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1150</td>
<td>Environmental Engineering Design</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. Or any other advanced Engineering course approved by the concentration advisor

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/

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 (1) - (7) 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 Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0030</td>
<td>Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0031</td>
<td>Honors Introduction to Engineering</td>
<td></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 0310</td>
<td>Mechanics of Solids and Structures</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0810</td>
<td>Fluid Mechanics</td>
<td></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>or MATH 0170</td>
<td>Advanced Placement Calculus</td>
<td></td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Intermediate Calculus (Physics/Engineering)</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0180</td>
<td>Intermediate Calculus</td>
<td></td>
</tr>
<tr>
<td>or MATH 0350</td>
<td>Honors Calculus</td>
<td></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></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>Applied Partial Differential Equations</td>
<td></td>
</tr>
<tr>
<td>or MATH 0520</td>
<td>Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>or APMA 1210</td>
<td>Operations Research: Deterministic Models</td>
<td></td>
</tr>
<tr>
<td>or APMA 1650</td>
<td>Statistical Inference I</td>
<td></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 Solving</td>
<td>1</td>
</tr>
</tbody>
</table>

2. Upper-Level Materials Engineering Curriculum

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1410</td>
<td>Physical Chemistry of Solids</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1420</td>
<td>Kinetics Processes in Materials Science and Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1440</td>
<td>Mechanical Properties of Materials</td>
<td>1</td>
</tr>
<tr>
<td>PHYS 0790</td>
<td>Physics of Matter</td>
<td>1</td>
</tr>
<tr>
<td>or CHEM 0350</td>
<td>Organic Chemistry</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: 3

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1450</td>
<td>Properties and Processing of Electronic Materials</td>
<td></td>
</tr>
<tr>
<td>ENGN 1470</td>
<td>Structure &amp; Properties of Nonmetallic Materials</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1475</td>
<td>Soft Materials</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1480</td>
<td>Metallic Materials</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1490</td>
<td>Biomaterials</td>
<td>1</td>
</tr>
</tbody>
</table>

3. Capstone Design

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1400</td>
<td>Projects in Engineering Design</td>
</tr>
<tr>
<td>or ENGN 1001</td>
<td>Projects in Engineering Design II</td>
</tr>
<tr>
<td>or ENGN 1930L</td>
<td>Biomedical Engineering Design and Innovation</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. These courses are taken in either the junior or senior year. Note that ENGN 1450, ENGN 1475, ENGN 1470 and ENGN 1480 are typically offered in alternate years.

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/
ENGN 0310 Mechanics of Solids and Structures 1
ENGN 0410 Materials Science 1
ENGN 0510 Electricity and Magnetism 1
ENGN 0520 Electrical Circuits and Signals 1
ENGN 0720 Thermodynamics 1
ENGN 0810 Fluid Mechanics 1
CHEM 0330 Equilibrium, Rate, and Structure 1
MATH 0190 Advanced Placement Calculus (Physics/ Engineering) 1
or MATH 0170 Advanced Placement Calculus

MATH 0200 Intermediate Calculus (Physics/ Engineering) 1
or MATH 0180 Intermediate Calculus
or MATH 0350 Honors Calculus

APMA 0330 Methods of Applied Mathematics I, II 1
or APMA 0350 Applied Ordinary Differential Equations

APMA 0340 Methods of Applied Mathematics I, II 1
or APMA 0360 Applied Partial Differential Equations I

CSCI 0040 Introduction to Scientific Computing and Problem Solving
or CSCI 0111 Computing Foundations: Data
or CSCI 0150 Introduction to Object-Oriented Programming and Computer Science
or CSCI 0170 Computer Science: An Integrated Introduction
or CSCI 0190 Accelerated Introduction to Computer Science
or APMA 0160 Introduction to Scientific Computing
or ENGN 1931Z Interfaces, Information and Automation

2. Upper-Level Mechanical Engineering Curriculum: Complete at least 6 courses from the following groups:

Mechanical Systems: At least one course from:
ENGN 1300 Structural Analysis
ENGN 1370 Advanced Engineering Mechanics
ENGN 1735 Vibration of Mechanical Systems
ENGN 1750 Advanced Mechanics of Solids

Fluids/Thermal Systems: At least one course from:
ENGN 1860 Advanced Fluid Mechanics
ENGN 1700 Aerospace Fluid Mechanics
ENGN 1710 Heat and Mass Transfer

Capstone: At least one course from the following must be taken in the final two semesters:
ENGN 1000 Projects in Engineering Design I
or ENGN 1001 Projects in Engineering Design II
ENGN 1930T Aircraft Design
ENGN 1930M Industrial Design
ENGN 1931D Design of Mechanical Assemblies
ENGN 1380 Design of Civil Engineering Structures
ENGN 1720 Design of Thermal Engines
ENGN 1760 Design of Space Systems

Design Electives: Up to two courses from:
ENGN 1230 Instrumentation Design
ENGN 1740 Computer Aided Visualization and Design

Bioengineering Electives: Up to two courses from:
ENGN 1210 Biomechanics
ENGN 1220 Neuroengineering
ENGN 1490 Biomaterials

Robotic and Control Systems Electives: up to two courses from:
ENGN 1931I Design of Robotic Systems
ENGN 1931Y Control Systems Engineering

Engineering Analysis and Computation Electives: up to two courses from:
ENGN 1840 Numerical Methods in Engineering
ENGN 1950 Advanced Engineering Optimization

Energy and Environmental Engineering Electives: up to two courses from:
ENGN 1930U Renewable Energy Technologies
ENGN 1931P Energy and the Environment

Interdisciplinary Electives: up to one course from:
ENGN 1620 Analysis and Design of Electronic Circuits
or ENGN 1340 Water Supply and Treatment Systems - Technology and Sustainability
or ENGN 1440 Mechanical Properties of Materials
or ENGN 1470 Structure & Properties of Nonmetallic Materials
or ENGN 1570 Linear System Analysis
or ENGN 1931F Introduction to Power Engineering
or ENGN 1931X Instrumentation for Research: A Biomaterials/ Materials Project Laboratory
or ENGN 1931Z Interfaces, Information and Automation

3. Upper-Level Advanced Science Course: at least one course from:
PHYS 0790 Physics of Matter
or BIOL 0800 Principles of Physiology
or CHEM 0350 Organic Chemistry
or CHEM 1140 Physical Chemistry: Quantum Chemistry
or EEPS 1450 Structural Geology
or EEPS 1370 Environmental Geochemistry

4. General Education Requirement: At least four approved courses must be taken in humanities and social sciences

Total Credits 21

1 ENGN 1490 may be substituted if taken in Sophomore year.
2 Other advanced courses in mathematics or applied mathematics may be substituted with approval of the concentration advisor.
3 Subject to approval by the concentration advisor, an independent study course (ENGN 1970/ENGN 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.
4 ENGN 1931Z may replace CSCI 0040 or meet an elective requirement, but not both.
5 Other non-introductory courses in physics, chemistry, neuroscience, geology, or biology may be substituted with the permission of the concentration advisor.

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 &amp; ENGN 0040</td>
<td>Introduction to Engineering and Dynamics and Vibrations (ENGN 0031 may be substituted for ENGN 0030)</td>
</tr>
<tr>
<td>PHYS 0050 &amp; PHYS 0060</td>
<td>Foundations of Mechanics and Foundations of Electromagnetism and Modern Physics</td>
</tr>
<tr>
<td>PHYS 0070 &amp; PHYS 0160</td>
<td>Analytical Mechanics and Introduction to Relativity, Waves and Quantum Physics</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Advanced Placement Calculus (Physics/Engineering)</td>
</tr>
<tr>
<td>or MATH 0170</td>
<td>Advanced Placement Calculus</td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Intermediate Calculus (Physics/Engineering)</td>
</tr>
<tr>
<td>or MATH 0180</td>
<td>Intermediate Calculus</td>
</tr>
<tr>
<td>or MATH 0350</td>
<td>Honors Calculus</td>
</tr>
</tbody>
</table>

Select three additional higher-level math, applied math, or mathematical physics (PHYS 0720) courses.

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSCI 0040</td>
<td>Introduction to Scientific Computing and Problem Solving</td>
</tr>
<tr>
<td>or APMA 0160</td>
<td>Introduction to Scientific Computing</td>
</tr>
<tr>
<td>or CSCI 0111</td>
<td>Computing Foundations: Data</td>
</tr>
<tr>
<td>or CSCI 0150</td>
<td>Introduction to Object-Oriented Programming and Computer Science</td>
</tr>
<tr>
<td>or CSCI 0170</td>
<td>Computer Science: An Integrated Introduction</td>
</tr>
<tr>
<td>or CSCI 0190</td>
<td>Accelerated Introduction to Computer Science</td>
</tr>
<tr>
<td>ENGN 0510</td>
<td>Electricity and Magnetism</td>
</tr>
<tr>
<td>or PHYS 0470</td>
<td>Electricity and Magnetism</td>
</tr>
<tr>
<td>ENGN 1560</td>
<td>Optics</td>
</tr>
<tr>
<td>or PHYS 1510</td>
<td>Advanced Electromagnetic Theory</td>
</tr>
<tr>
<td>PHYS 0500</td>
<td>Advanced Classical Mechanics</td>
</tr>
<tr>
<td>or ENGN 1370</td>
<td>Advanced Engineering Mechanics</td>
</tr>
<tr>
<td>PHYS 1410</td>
<td>Quantum Mechanics A</td>
</tr>
<tr>
<td>PHYS 1420</td>
<td>Quantum Mechanics B</td>
</tr>
<tr>
<td>PHYS 1530</td>
<td>Thermodynamics and Statistical Mechanics</td>
</tr>
<tr>
<td>or ENGN 0720</td>
<td>Thermodynamics</td>
</tr>
<tr>
<td>ENGN 1620</td>
<td>Analysis and Design of Electronic Circuits</td>
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<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
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<tr>
<td>or ENGN 0310</td>
<td>Mechanics of Solids and Structures</td>
</tr>
<tr>
<td>or ENGN 0810</td>
<td>Fluid Mechanics</td>
</tr>
<tr>
<td>or PHYS 1600</td>
<td>Computational Physics</td>
</tr>
<tr>
<td>ENGN 0410</td>
<td>Materials Science</td>
</tr>
<tr>
<td>or ENGN 1690</td>
<td>Photonics Devices and Sensors</td>
</tr>
<tr>
<td>or PHYS 0560</td>
<td>Experiments in Modern Physics</td>
</tr>
<tr>
<td>PHYS 1560</td>
<td>Modern Physics Laboratory</td>
</tr>
<tr>
<td>or ENGN 1590</td>
<td>Introduction to Semiconductors and Semiconductor Electronics</td>
</tr>
<tr>
<td>or an approved 2000-level engineering or physics course,</td>
<td></td>
</tr>
<tr>
<td>A thesis under the supervision of a physics or engineering faculty member;</td>
<td></td>
</tr>
<tr>
<td>PHYS 1990</td>
<td>Senior Conference Course</td>
</tr>
<tr>
<td>or ENGN 1970</td>
<td>Independent Studies in Engineering</td>
</tr>
<tr>
<td>or ENGN 1971</td>
<td>Independent Study in Engineering</td>
</tr>
</tbody>
</table>

* Students are also encouraged to take courses dealing with the philosophical, ethical, or political aspects of science and technology.

Total Credits 19

**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 or for graduate study in BME and related fields; (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 ABET (1) - (7) 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

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0030</td>
<td>Introduction to Engineering</td>
</tr>
<tr>
<td>or ENGN 0031</td>
<td>Honors Introduction to Engineering</td>
</tr>
<tr>
<td>ENGN 0040</td>
<td>Dynamics and Vibrations</td>
</tr>
<tr>
<td>ENGN 0510</td>
<td>Electricity and Magnetism</td>
</tr>
<tr>
<td>or ENGN 0520</td>
<td>Electrical Circuits and Signals</td>
</tr>
<tr>
<td>ENGN 0720</td>
<td>Thermodynamics</td>
</tr>
<tr>
<td>ENGN 0810</td>
<td>Fluid Mechanics</td>
</tr>
<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
</tr>
<tr>
<td>CHEM 0350</td>
<td>Organic Chemistry</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Advanced Placement Calculus (Physics/Engineering)</td>
</tr>
<tr>
<td>or MATH 0170</td>
<td>Advanced Placement Calculus</td>
</tr>
<tr>
<td>or MATH 0100</td>
<td>Introductory Calculus, Part II</td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Intermediate Calculus (Physics/Engineering)</td>
</tr>
<tr>
<td>or MATH 0180</td>
<td>Intermediate Calculus</td>
</tr>
<tr>
<td>or MATH 0350</td>
<td>Honors Calculus</td>
</tr>
<tr>
<td>APMA 0330</td>
<td>Methods of Applied Mathematics I, II</td>
</tr>
<tr>
<td>or APMA 0350</td>
<td>Applied Ordinary Differential Equations</td>
</tr>
<tr>
<td>APMA 1650</td>
<td>Statistical Inference I</td>
</tr>
<tr>
<td>or BIOL 0495</td>
<td>Statistical Analysis of Biological Data</td>
</tr>
<tr>
<td>or PHP 1510</td>
<td>Principles of Biostatistics and Data Analysis</td>
</tr>
<tr>
<td>or APMA 1655</td>
<td>Statistical Inference I</td>
</tr>
</tbody>
</table>
2. Upper Level Biomedical Engineering Curriculum

<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 1210</td>
<td>Biomechanics</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1230</td>
<td>Instrumentation Design</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1490</td>
<td>Biomaterials</td>
<td>1</td>
</tr>
<tr>
<td>BIOL 0800</td>
<td>Principles of Physiology</td>
<td>1</td>
</tr>
</tbody>
</table>

3. Additional Biomedical Engineering Electives (Complete at least 3 courses from the following groups):

- ENGN 1220 Neuroengineering
- ENGN 1510 Nanoengineering and Nanomedicine
- ENGN 1520 Cardiovascular Engineering
- ENGN 1930B Biomedical Optics
- ENGN 2910S Cancer Nanotechnology
- ENGN 2912R Implantable Devices
- BIOL 1140 Tissue Engineering
- CSCI 1810 Computational Molecular Biology
- or CSCI 1820 Algorithmic Foundations of Computational Biology
- ENGN 0500 Digital Computing Systems
- ENGN 1740 Computer Aided Visualization and Design
- ENGN 2911R Analytical Modeling for Biomechanical and Biomedical Systems
- ENGN 2625 Optical Microscopy: Fundamentals and Applications
- BIOL 1150 Stem Cell Engineering
- BIOL 2110 Drug and Gene Delivery

4. Capstone Design

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1930L</td>
<td>Biomedical Engineering Design and Innovation</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1931L</td>
<td>Biomedical Engineering Design and Innovation II</td>
<td>1</td>
</tr>
</tbody>
</table>

5. General Education Requirement: At least four approved courses must be taken in the humanities and social sciences.

Entrepreneurship Concentration Requirements

Offered by the Nelson Center for Entrepreneurship, in partnership with Brown’s School of Engineering, the Certificate in Entrepreneurship equips students with an understanding of the fundamental building blocks of the entrepreneurial process: i) understanding and validating an unmet need; ii) developing a value proposition that addresses an unmet need; and iii) designing a sustainability model that allows the value proposition to be delivered repeatedly at scale. Two core courses introduce students to foundational entrepreneurial concepts. Two elective courses will extend students’ foundational work into areas of particular interest. Finally, students will complete an entrepreneurship practicum that enables them to apply what they have learned in the classroom to a real-world project of interest.

As with all undergraduate certificates ([https://www.brown.edu/academics/college/degree/undergraduatedecertificates/](https://www.brown.edu/academics/college/degree/undergraduatedecertificates/)), students must be enrolled in or have completed at least two courses toward the certificate at the time they declare in ASK, which must be no earlier than the beginning of the fifth semester and no later than the last day of classes of the antepenultimate (typically the sixth) semester, in order to facilitate planning for the entrepreneurship practicum. Students must submit a proposal for their practicum project by the end of the sixth semester.

Excluded Concentrations: Business, Entrepreneurship, & Organizations (BEO)

Certificate Requirements

Core Courses:

- ENGN 0090 Management of Industrial and Nonprofit Organizations 1
- ENGN 1010 The Entrepreneurial Process: Innovation in Practice 1

Elective Courses (choose two):

- BIOL 2089 The Importance of Intellectual Property in Biotechnology 2
- CSCI 1900 csciStartup
- ECON 1490 Designing Internet Marketplaces
- ECON 1730 Venture Capital, Private Equity, and Entrepreneurship
- ENGN 0020 Transforming Society-Technology and Choices for the Future
- ENGN 0900 Managerial Decision Making
- ENGN 0110 Lean LaunchPad
- ENGN 1931Q Entrepreneurial Management in Adversity
- ENGN 1931W Selling & Sales Leadership in the Entrepreneurial Environment
- IAPA 1803E Social Entrepreneurship
- SOC 1260 Market Research in Public and Private Sectors

Practicum: 1

Students must complete an Entrepreneurship Practicum (EP), an experiential semester course that enables them to apply what they have learned in the classroom to real-world projects. Students will apply the entrepreneurial process to a challenge or problem that is important to them, perhaps evolving from one of their other courses. The Practicum will act as a laboratory to identify and develop an impactful solution to that problem.

Total Credits 5

Students must submit a proposal for their practicum project by the end of the sixth semester.

Engineering Graduate Program

The School of Engineering directly offers graduate programs leading to the Master of Science (Sc.M.) degree; the Master of Science in Innovation...
Management and Entrepreneurship (Sc.MIME); and the Doctor of Philosophy (Ph.D.) degree.

In addition, the School of Engineering in collaboration with the Division of Biology and Medicine offers an interdisciplinary program leading to the Master of Science (Sc.M.) and 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/ (http://www.brown.edu/academics/gradschool/programs/engineering/)

**Master of Science (Thesis Option)**

- Candidates must complete a coherent plan of study based in engineering or engineering science consisting of nine graduate or advanced level courses and an acceptable thesis, which is normally sponsored by a member of the engineering faculty.

  - The program must include ENGN 2010 and ENGN 2020 (Mathematical Methods in Engineering and Physics) or their equivalent (must be 2000 level)

  - For some programs, ENGN 2010 and/or ENGN 2020 can be replaced by an alternate/applied mathematics course or 2000-level engineering/science course. This substitution can only be made with the approval of the appropriate Graduate Representative and the Director of Graduate Studies. The final program must contain at least one advanced mathematics/applied mathematics course.

  - Two additional 2000-level engineering courses other than ENGN 2980 (Special Projects: Reading Research and Design) must be included.

  - Three additional 2000-level engineering courses other than ENGN 2980 (Special Projects: Reading Research and Design) must be included. Courses in engineering management (PRIME) are not acceptable for use as one of the 2000-level engineering classes.

  - The remaining courses may include up to two ENGN 2980 class and up to three 1000-level Engineering, other approved science classes or PRIME classes. Students should choose courses in consultation with the student’s advisor to develop a coherent program.

  - The proposed program of study must be approved by the Director of Graduate Programs in the School of Engineering.

For students in the Master of Science in Engineering program (thesis option,) the approved course sequence is 2-2-2-2, where the student takes two courses in each semester. However, the program strongly recommends a sequence of 3-2-2-1 where the student takes 3 courses the first semester, 2 the second, 2 the third, and 1 the fourth. Any deviation from this schedule can result in additional tuition and/or penalties.

Note: students enrolled in the Ph.D. program, including first-year fellowship students, should understand that an application to receive a non-thesis Sc.M. in engineering must be approved by the student's research advisor.

**Master of Science (Non-Thesis Option)**

- Candidates must complete a coherent plan of study based in engineering or engineering science consisting of eight graduate or advanced level courses.

  - The program must include ENGN 2010 and 2020 (Mathematical Methods in Engineering and Physics) or their equivalent (must be 2000 level)

  - For some programs, ENGN 2010 and/or ENGN 2020 can be replaced by an alternate/applied mathematics course or 2000-level engineering/science course. This substitution can only be made with the approval of the appropriate Graduate Representative and the Director of Graduate Studies. The final program must contain at least one advanced mathematics/applied mathematics course.

  - Three additional 2000-level engineering courses other than ENGN 2980 (Special Projects: Reading Research and Design). Courses in engineering management (PRIME) are not acceptable for use as one of the 2000-level engineering classes.

  - The remaining courses may include one ENGN 2980 class and up to three 1000-level Engineering, other approved science classes or PRIME classes. Students should choose courses in consultation with the student’s advisor to develop a coherent program.

  - The proposed program of study must be approved by the Director of Graduate Programs in the School of Engineering.

For students in the Master of Science in Engineering program (non-thesis option), the approved course sequence is 3-3-2, meaning the student takes 3 courses the first semester, 3 the second, and 2 the third. Any deviation from this schedule can result in additional tuition and/or penalties.

Note: students enrolled in the Ph.D. program, including first-year fellowship students, should understand that an application to receive a non-thesis Sc.M. in engineering must be approved by the student's research adviser.

**Master of Science (Non-Thesis Option)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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<tbody>
<tr>
<td>PHYS 2020</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 2010</td>
<td></td>
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<tr>
<td>ENGN 2020</td>
<td>1</td>
</tr>
<tr>
<td>Two additional 2000-level ENGN courses (other than ENGN 2980)</td>
<td>2</td>
</tr>
<tr>
<td>Three additional Engineering or approved science courses (not more than two 1000 level courses)</td>
<td>3</td>
</tr>
<tr>
<td>ENGN 2980</td>
<td>1</td>
</tr>
<tr>
<td>Total Credits</td>
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</table>

**Physics (Ph.D.)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical Methods of Engineers and Physicists</td>
<td>1</td>
</tr>
<tr>
<td>Mathematical Methods of Engineers and Physics I</td>
<td>1</td>
</tr>
<tr>
<td>Mathematical Methods in Engineering and Physics II</td>
<td>1</td>
</tr>
<tr>
<td>Two additional 2000-level ENGN courses (other than ENGN 2980)</td>
<td>2</td>
</tr>
<tr>
<td>Four additional ENGN or approved science courses (up to 3 may be 1000-level ENGN)</td>
<td>4</td>
</tr>
<tr>
<td>Total Credits</td>
<td>8</td>
</tr>
</tbody>
</table>

**Master of Science (Non-Thesis Professional Track Option)**

- Candidates must complete a coherent plan of study based in engineering or engineering science consisting of eight graduate or advanced level courses.

  - The program must include ENGN 2010 and 2020 (Mathematical Methods in Engineering and Physics) or their equivalent (must be 2000 level).

  - For some programs, ENGN 2010 and/or ENGN 2020 can be replaced by an alternate/applied mathematics course or 2000-level engineering/science course. This substitution can only be made with the approval of the appropriate Graduate Representative and the Director of Graduate Studies. The final program must contain at least one advanced mathematics/applied mathematics course.

  - The remaining courses may include one ENGN 2980 class and up to three 1000-level Engineering, other approved science classes or PRIME classes. Students should choose courses in consultation with the student’s advisor to develop a coherent program.

  - The proposed program of study must be approved by the Director of Graduate Programs in the School of Engineering.
- Three additional 2000-level engineering courses other than ENGN 2980 (Special Projects: Reading Research and Design). Courses in engineering management (PRIME) are not acceptable for use as one of the 2000-level engineering classes.

- The remaining courses may include one ENGN 2980 class and up to three 1000-level Engineering, other approved science classes or PRIME classes. Students should choose courses in consultation with the student’s adviser to develop a coherent program.

- A paid or unpaid internship is a required component of the program. All internships must be pre-approved by the School of Engineering. Assistance in obtaining internships will be provided by the School and Brown CareerLAB.

- The proposed program of study must be approved by the Director of Graduate Programs in the School of Engineering.

- For students in the Master of Science in Engineering program (non-thesis option,) the approved course sequence is 3-3-2, meaning the student takes 3 courses the first semester, 3 the second, and 2 the third. Any deviation from this schedule can result in additional tuition and/or penalties.

**Professional Track Internship Information**
Internships are traditionally utilized during the first summer of the Sc.M. program. You should however start early (January is generally recommended) to try and find a suitable internship. Please refer to the CareerLAB guidelines and recommendations (https://www.brown.edu/campus-life/support/careerlab) for resume preparation, interviewing, and general procedures about which you should be aware when deciding on an internship.

The following resources will help you search for an opportunity that fits your goals:

- The School of Engineering distributes a weekly undergraduate and graduate newsletter that contains many internship opportunities, both at Brown and elsewhere. Email distribution of the newsletter occurs every Monday throughout the academic year.


- Brown has an AfterCollege (https://www.aftercollege.com/career-networks/brown-university/) page that lists both full-time positions and internships.

- The School of Engineering runs a Career and Internship Fair toward the end of fall semester or early in the spring semester of each year. Check the School of Engineering calendar for announcements.

- BrownConnect (https://brownconnect.brown.edu/) is a networking tool that allows you to contact Brown alumni for advise, networking, and mentoring. The database includes their companies, titles, and is searchable by key words.

- Fill out the internship approval form (https://www.brown.edu/academics/engineering/sites/brown.edu.academics.engineering/files/uploads/Internship%20Approval%20Form.pdf) and submit it to Associate Dean Jennifer Casasanto (Jennifer_Casasanto@Brown.edu) before the end of the semester (or earlier if you are intending to get CPT approval from OISSS). You should NEVER begin work before your internship is approved.

**Master of Science: Program in Innovation Management and Entrepreneurship (PRIME)**

<table>
<thead>
<tr>
<th>Program in Innovation Management and Entrepreneurship (PRIME) requirements</th>
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</thead>
<tbody>
<tr>
<td>ENGN 2110</td>
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<tr>
<td>ENGN 2120</td>
</tr>
<tr>
<td>ENGN 2125</td>
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<tr>
<td>ENGN 2150</td>
</tr>
<tr>
<td>ENGN 2160</td>
</tr>
<tr>
<td>ENGN 2180</td>
</tr>
</tbody>
</table>

Two 1000-level or above electives. Must be approved by PRIME advisor.

**Total Credits** 8

For more information on admission and program requirements for the Program in Innovation Management and Entrepreneurship Engineering (PRIME), please visit the following website: http://www.brown.edu/academics/gradschool/programs/innovation-management-and-entrepreneurship-engineering (http://www.brown.edu/academics/gradschool/programs/innovation-management-and-entrepreneurship-engineering/)

**Other Sc.M. Requirements**
International students must be full-time at all times throughout their academic program, with few exceptions.

**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.

**ENGN 0030. Introduction to Engineering.**
ENGN 0030 introduces students to the engineering profession and the important role engineers play in society. The course content begins with engineering design, followed by the analysis of static structures. Topics also include Computer Aided Design, basic Matlab programming, professional ethics, and social responsibility. Students complete group training modules and design projects in the Brown Design Workshop, led by an undergraduate mentor. ENGN 0030 provides the foundation for further study in engineering. It should be taken by students considering concentrating in engineering, interested in the entrepreneurship curriculum, and curious about engineering and design. Students should be enrolled in MATH 0100 or higher.

Fall ENGN0030 M01 16510 MWF 12:00-1:50 (K. Haberstroh)
Fall ENGN0030 S01 15853 T 12:00-1:20(08) (D. Pacifici)

**Master of Science (Non-Thesis Professional Track Option)**

| PHYS 2020          | Mathematical Methods of Engineers and Physicists | 1 |
| or ENGN 2010       | Mathematical Methods in Engineering and Physics I | 1 |
| ENGN 2020          | Mathematical Methods in Engineering and Physics II | 1 |

Two additional 2000-level Engineering courses (other than ENGN 2980) | 2 |
**ENGN 0031. Honors Introduction to Engineering.** ENGN0031 introduces students to the engineering profession and the important role engineers play in society. The course content begins with engineering design, followed by the analysis of static structures. Topics also include CAD and extensive Matlab programming, professional ethics, and social responsibility. Students complete group training modules and design projects in the Brown Design Workshop. ENGN0031 provides the foundation for further study in engineering. Students pursuing Mechanical, Electrical or Materials Engineering who complete the Honors course may substitute an approved Engineering or Computer Science course in place of CSCI 0040. Students should be enrolled in MATH 0170 or higher.

**ENGN 0032. Introduction to Engineering: Design.** This course is an introduction to the engineering profession with an emphasis on design. It is a project-based class which consists of three major design projects. Working in small groups, students leverage the design process and engineering discipline to present solutions to three design briefs. In weekly studio sessions, students will learn different tools associated with engineering and design. ENGN 0032 provides the foundation for further study in engineering. This class is designed for students who have a strong interest in design or are unsure of their interest in engineering. Students should also enroll in MATH 0100 or higher.

<table>
<thead>
<tr>
<th>Fall</th>
<th>ENGN0032 S01 17570 MWF 1:00-1:50(06)</th>
<th>(M. Donohue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>ENGN0032 L01 17849 TTh 6:00-7:30</td>
<td>(M. Donohue)</td>
</tr>
</tbody>
</table>

**ENGN 0400. Dynamics and Vibrations.** A broad introduction to Newtonian dynamics of particles and rigid bodies with applications to engineering design. Concepts include kinematics and dynamics of particles and rigid bodies; conservation laws; vibrations of single degree of freedom systems; and use of MATLAB to solve equations of motion and optimize engineering designs. Examples of applications are taken from all engineering disciplines. Lectures, recitation, and team design projects, including use of Brown Design Workshop. Prerequisite: ENGN 0030. Corequisite: MATH 0200 or MATH 0180.

**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.

**ENGN 0110. Lean LaunchPad.** The Lean LaunchPad (LLP) is a Wintersession course on how to build a startup using lean startup tools and frameworks. It is a hands-on, intensive, experiential course designed for student teams who are serious about pursuing a startup. The course teaches development of relationships with customers, suppliers, communications providers and other enablers of the business with immediate feedback, requiring students to get out of the building and test their business hypotheses through multiple in-person meetings. The Business Model Canvas is the scorecard for contact effectiveness and for development of the ecosystem of contacts which will make the business viable.

**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.

**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.

**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 19 first year students.

**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.

**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 0310. Mechanics of Solids and Structures.** 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.

<table>
<thead>
<tr>
<th>Fall</th>
<th>ENGN0310 S01 16320 MWF 11:00-11:50(16)</th>
<th>(B. Hazeltine)</th>
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</thead>
<tbody>
<tr>
<td>Fall</td>
<td>ENGN0310 C01 16513 T 12:00-12:50</td>
<td>(P. Guduru)</td>
</tr>
<tr>
<td>Fall</td>
<td>ENGN0310 C02 16514 T 5:00-5:50</td>
<td>(P. Guduru)</td>
</tr>
</tbody>
</table>
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 and optical properties of materials; strengthening mechanisms in solids and relationships between microstructure and properties. Lectures, recitations, laboratory.
Fall ENGN0410 S01 16269 M 9:00-10:20(02) (E. Chason)
Fall ENGN0410 C01 16515 W 1:00-1:50 (E. Chason)
Fall ENGN0410 C02 16516 W 3:00-3:50 (D. Painé)
This course presents a broad introduction to environmental engineering, and will help students to explore environmental engineering as an academic major and as career option. The course covers topics in environmental engineering: chemistry fundamentals, mass balance, air pollution, water pollution, sustainable solid waste management and global atmospheric change. The course is essential for the environmental engineering students who are planning to take more advanced courses in environmental engineering. This course is also for the students in other engineering disciplines and sciences, who are interested in environmental constraints on technology development and practice, which have become increasingly important in many fields.
Fall ENGN0490 S01 16529 TTh 1:00-2:20(08) (K. Pennell)

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 16521 MWF 10:00-10:50(14) (D. Mittleman)

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 early and stressed throughout. Other topics include circuit theorems, power transfer, transient analysis, Fourier series, Laplace transform, 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 ENGN0520 S01 16528 MWF 11:00-11:50(16) (T. Powers)

ENGN 0520L. Electromagnetics and Electromechanics.
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: MATH 0180 or MATH 0200, courses may be taken concurrently to ENGN 0520.

ENGN 0720. Thermodynamics.
This course introduces the study of design, engineering, work, material culture and history through the construction of a traditional workboat, a Maine Peapod. As the class builds the boat, we’ll gain hands-on understanding of issues of engineering, design, skill, and workmanship. We will do historical research and visit museums to gain insight into the history of small craft and their builders/users from the nineteenth century to the present. Throughout the course, we will consider philosophical issues of tradition, creativity, and knowledge in engineering and making. Three longer writing assignments and an ongoing journal will connect hands-on work and research.

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.

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.

ENGN 0930C. DesignStudio.
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.

ENGN 0930L. Biomedical Engineering Design and Innovation.
This course is an incubator for innovative ideas in biomedical design. Students across all disciplines are invited to collaborate with biomedical engineers to enhance the development of design solutions that address clinical and public health concerns. Students will form teams with their peers and a clinical advisor, identify and define a design project to meet a clinical need, and engage in the design process throughout the semester. Engineering concentrators should register for ENGN1930L.

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.

ENGN 0931L. Biomedical Engineering Design and Innovation II.
This course is an incubator for innovative ideas in biomedical design. Students across all disciplines are invited to collaborate with biomedical engineers to enhance the development of design solutions that address clinical and public health concerns. Student teams formed in the previous semester will continue develop a design project based on an unmet clinical need with a clinical advisor, gaining hands-on process experience and generating innovative solutions. Engineering concentrators should register for ENGN 1931L.
ENGN 1000. Projects in Engineering Design I.
Fall semester projects in design for concentrators in electrical, materials, and mechanical engineering. Students 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. Students may elect to combine ENGN 1000 with ENGN 1001 to work on a year-long project with permission of the instructor. Students electing to pursue this option must take ENGN 1000 and ENGN 1001 in the same academic year, and must submit a project proposal no later than October 1. Instructor permission required.
Fall ENGN1000 S01 16539 M 3:00-5:30 (J. Fontaine)

ENGN 1001. Projects in Engineering Design II.
Spring semester projects in design for concentrators in electrical, materials, and mechanical engineering. Students work in teams on projects defined through discussions with instructor. An assembled product or detailed design description is the goal of semester’s effort. Students may elect to combine ENGN 1000 with ENGN 1001 to work on a year-long project with permission of the instructor. Students electing to pursue this option must take ENGN 1000 and ENGN 1001 in the same academic year and must have submitted a project proposal by October 1 of the previous Fall semester. Instructor permission required.

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.
Fall ENGN1010 S01 16543 TTh 10:30-11:50(13) (D. Warshay)
Fall ENGN1010 S02 16544 M 6:00-8:30PM (J. Cohen)
Fall ENGN1010 S03 16545 W 3:00-5:30 (F. Slutsky)

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. Prerequisite: Junior level or higher standing. Offered in alternate years.
Fall ENGN1110 S01 16530 TTh 10:30-11:50(13) (D. Borton)
Fall ENGN1110 S02 16531 MWF 10:00-10:50(14) (R. Goldsmith)

ENGN 1120. Reaction Kinetics and Reactor Design.
Mechanisms, driving forces, and rate expressions of homogeneous and heterogeneous chemical and biochemical systems. Kinetics described from the potential energy surface to reaction networks. Basic concepts in reactor design and idealized reactor models. Chemostats and enzymatic reactors. Optimization. Temperature and energy effects in reactors. Catalysts and coupled transport effects. Prerequisite: ENGN 0720 or equivalent. Offered in alternate years.
Fall ENGN1120 S01 16539 TTh 2:30-3:50(12) (F. Goldsmith)

ENGN 1130. Chemical Engineering Thermodynamics.
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 or equivalent. Offered in alternate years.

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 or Corequisites: ENGN 1110, 1120, 1130.

ENGN 1210. Biomechanics.
Important foundations of continuum biomechanics, properties and behavior of biomaterials, three-dimensional concepts of strains and stress, linear isotropic elasticity, anisotropic response, yield, fracture, fatigue, nonlinear elastic and viscoelastic response of biological materials/structures and biomedical implants will be taught. Students will learn physical basis, theory, modeling and applications of each of these topics with relevance to biomedical engineering. Muscle biomechanics, biomechanics of walking and running and response of soft tissue and bone will be discussed. Prerequisite: APMA 0330 or equivalent. Lectures and laboratory.

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 neurotechnologies. Prerequisites: NEUR 0010 and ENGN 0510; or instructor permission, which may be provided after discussion with course faculty.

ENGN 1230. Instrumentation Design.
Fall ENGN1230 S01 16300 MWF 10:00-10:50(14) (D. Borton)

ENGN 1300. Structural Analysis.
Classical and modern methods of analysis for statically determinate structures. Development of computer programs for the analysis of civil, mechanical, and aerospace structures from the matrix formulation of the classical structural theory, through the direct stiffness formulation, to production-type structural analysis programs. Introduction to Finite Element Methods (FEM) and Isogeometric Analysis (IGA). Prerequisite: ENGN 0310.

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

ENGN 1340. Water Supply and Treatment Systems - Technology and Sustainability.
This course provides a comprehensive overview of engineering approaches how to protect water quality. Class begins with brief introduction to hydrological cycle. More in detail groundwater flows (Darcy eq. -n) and flows into wells are examined. Principles of hydraulics are presented. Open channel and river flows, flood routing and preventing are presented. Freshwater and wastewater treatment technologies, together with advanced water treatment processes evaluated. Course ends with the visit to a local wastewater treatment plant. Prerequisites: CHEM 0330 and ENGN 0040. Recommended ENGN 0810.

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.
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.

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, florescence 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 metalurgy. 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.

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.

Begin with basic concepts of mechanical properties common to all materials, with some emphasis on dislocation theory. Particular attention is given to the relationship between mechanical properties and microstructures. The different types of mechanical tests that are used in each of these fields are analyzed. Lectures plus laboratories. Prerequisite: ENGN 0410.

Focus on fundamental properties, processing, and characterization of electronic materials for microelectronic, large area, and thin film device applications. Processing Si into modern integrated circuits, e.g., VLSI, USLI, will be described in terms of materials science of unit processes (oxidation, lithography, diffusion, ion implantation, thin film deposition) used in device fabrication. Review relationship between properties of different materials classes (metals, semiconductors, insulators) and band structure. Concepts used to explain the operation of a p-n junction and simple MOS structures. Laboratory will focus on depositing materials via vapor phase synthesis methods and measuring fundamental electronic properties of materials using transport measurements.

A study of the structure and properties of nonmetallic materials such as glasses, ceramics, and polymers. The crystal structure of ceramics, and the noncrystalline, chain and acyclic structures of glasses and polymers, and the generation of microstructures and composites are considered. The physical and mechanical properties of glasses, ceramics, polymers, and composites, and their dependence on structure, are developed. Prerequisite: ENGN 0410.

ENGN 1480. Metallic Materials.
The central theme is to familiarize students with typical microstructures in metals and alloys, their origin, and factors that control stability. The role of processing (primary and secondary) in influencing microstructures will be demonstrated. The ability to change microstructure through composition and processing to obtain a "desired" microstructure that provides specific properties will be highlighted with examples in different alloy systems including Al, steels, and Ni-based. Factors that control stability and shape of second phase particles will be discussed for L/S and S/S processing. The consequences of microstructural changes on physical and mechanical properties will be illustrated. Prerequisite: ENGN 0410, ENGN 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 16301 Th 4:00-6:30 (A. Van De Walle)

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. Medical applications of these materials will include drug delivery, imaging and diagnostics, and tissue engineering approaches. Nanotoxicology will also be discussed. Research methods in nanoengineering and nanomedicine will be emphasized (i.e., critical analysis of scientific literature, effective oral and written communication). Students will also have the opportunity to gain an introduction to several nanoengineering research tools available on campus. This course is for engineering and science graduate students and advanced upper-level engineering undergraduates.

ENGN 1520. Cardiovascular Engineering.
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.

ENGN 1550. Optics.
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.

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.

This course will cover digital design and implementation concepts required for successful tape-out of integrated circuits. The first part covers the fundamentals of Very Large-Scale Integration (VLSI) design, including transistor analysis, standard cell layout, and cell characterization techniques. The second part covers use of design automation tools to complete a full design to tape-out. In the second part, hardware design using Verilog will be first discussed, and then will follow with the use of techniques and tools: logic synthesis, circuit timing and power, and placement and routing. The class will feature a number of labs and a large design project.

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.

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.

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.

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 description 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.

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 microcircuit 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.

ENGN 1690. Photonics Devices and Sensors.
Science and engineering principles of photonics and optoelectronic devices that provide foundation to a broad range of technologies from lasers to detectors, from cameras to computer displays, from solar cells to molecular sensing, from internet to quantum cryptography, and to new lighting sources for illuminations in the city and in biomedical treatments. Topical content: Light as waves in media, on surfaces, and through micro and nanostructures; interference and waveguiding; light generation by spontaneous emission, stimulated emissions, photodetection, infrared and night visions, LED, lasers, optical amplifiers and modulators, etc. Prerequisite: ENGN 0510 or equivalent.

Advanced fluid mechanics focusing on the physics, concepts, theories, and models of aerodynamics, turbomachinery, and space propulsion. Topics will focus on airfoil and wing theory; laminar and turbulent boundary layers; sub- and supersonic aerodynamics. Introduction to rocket propulsion and advanced space propulsion. Lectures, labs, computation and design projects. Prerequisites: ENGN 0720 and ENGN 0810.

Steady 1D and 2D heat conduction with heat generation. Transient heat conduction. Forced convection, heat convection during external and internal flows. Natural convection. Heat Exchangers. Thermal radiation, Kirchhoff's law, the perfect emitter, radiation intensity and surface emissive power, real surface radiation; view factors for black and gray surfaces. Diffusion mass transfer. Lectures and labs. Prerequisite: ENGN 0810.

ENGN 1720. Design of Thermal Engineers.
Students will work in groups on semester long engine design projects. Projects are to incorporate: formulation of design problem statements and specifications, consideration of alternative solutions, detailed design descriptions, development and use of design methodology, development of student creativity and use of acquired engineering skills, while including realistic constraints such as economic factors, safety, reliability, ethics, social impact, etc. Lectures, laboratory, and computer aided design projects with oral and written reports. Lectures to cover: thermodynamics, heat transfer, fluid dynamics, kinematics/dynamics, lubrication, combustion, fuels, and pollution of thermal engines. Prerequisites: ENGN 0720 and 0810.

ENGN 1735. Vibration of Mechanical Systems.
This course will focus on the vibration characteristics of mechanical systems. Topics will include: analysis of free and forced single degree-of-freedom linear oscillators, vibration control and isolation, multiple degree-of-freedom and continuous systems, and introduction to nonlinear oscillations. Relevant analytical and numerical methods useful for modeling and analysis of vibrating systems will be discussed throughout. Students will be expected to do some numerical calculations on a computer.

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.
Continuum mechanics of solids and its application to the mechanical response of machine and structural elements. Tensor descriptions of deformation and internal forces in solids; field equations. Elastic and elastic-plastic material models; failure criteria. Analytical techniques and energy methods for elastic solids; implementing the finite element method for elastic solids. Beam and plate theory. Stress waves and vibrations in solids. Use of commercial finite element software. Prerequisite: ENGN 0310. APMA 0330.
Fall ENGN1750 S01 16317 TTh 10:30-11:50(13) (D. Henann)

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. Prerequisite: Engineering core curriculum or equivalent.
Numerical analysis techniques related to solving systems of linear algebraic equations, matrix eigenvalue problems, nonlinear equations, polynomial approximation and interpolation, numerical integration and differentiation, ordinary and partial differential equations. Programming in Matlab. Pre-req: ENGN0040, CSCI 0040 or equivalent programming ability. APMA 0330, APMA 0340 or equivalent.

This course, through substantial projects, deepens student’s understanding of the design principles and processes and develops their skill at synthesizing artifacts that are appropriate responses to situations in specific contexts. It asks students to acquire new knowledge of a physical and social context and to integrate this new knowledge with their world model to create artifacts that produces a positive change in the context.

Aims to give students a deeper and more thorough grounding in principles and applications of fluid mechanics. Topics include review of dimensional analysis and conservation principles; viscous flows with application to microfluidics; lubrication analysis for bearing design; laminar boundary layers; wave motion; and interfacial phenomena (e.g., drops and bubbles). Lectures, assignments, computational projects, and laboratory. Prerequisites: ENGN 0810.

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 fellows 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 polygonal models. Applications include computer animation, game development, electronic commerce, heritage preservation, reverse engineering, and virtual reality.

ENGN 1930B. Biomedical Optics.
Biomedical optics is a rapidly growing field with applications in medicine, biology, and neuroscience. The course covers principles and applications of wave optics for biomedical imaging. The principles include refraction, reflection, scattering, diffraction and interference. The applications include Michelson interferometry and optical coherence tomography (OCT). OCT is the emerging technology for 3D imaging, considered by the American Institute for Medical and Biological Engineering (AIMBE) as the latest innovation milestone in the history of biomedical engineering. Throughout the course, we will also learn various numerical analysis techniques with working examples in MATLAB. Prerequisites: Undergraduate level ENGN 0510 Minimum Grade of S

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.

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

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 and Innovation.
This course is the culmination “capstone” of the biomedical engineering educational experience. The primary objective of this course is to recall and enhance design principles introduced through the engineering core curriculum and to apply this systematic set of engineering design skills to biomedical engineering projects. Students will form teams with their peers and a clinical advisor, identify and define a design project to meet a clinical need, and engage in the design process through the course of the semester. For seniors only. Non-engineering concentrators should register for ENGN 0930L.

Fall ENGN1930L S01 16311 MW 8:30-9:50(01) (C. Kofron)
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.

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 1930R. 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. Aircraft Design.
The process of aircraft conceptual design as practiced in industry: requirements definition to initial sizing, configuration layout, analysis, sizing, optimization, and trade-off studies. Concepts and calculation methods for aerodynamics, stability and control, propulsion, structures, weights, performance, and cost; coverage of conventional and unconventional design methods drawing from knowledge gained in engineering science courses, synthesized towards novel imaginative aircraft designs guided by participants’ interests. Prerequisite: the level of senior in engineering studies.

ENGN 1930U. Renewable Energy Technologies.
Renewable Energy Technology examines energy conversion, transport, and storage with the goal of devising courses of action that transform the current state of energy use into one that relies more fully on renewable resources and efficient processes. The course will give priority to photovoltaics, wind, and hydro conversion technologies and to the electrical grid for energy transport. From year-to-year other topics will be explored based on the wishes of the participants. Research, discussion, projects, and presentations will be the primary learning methods. The engineering core and thermodynamics are suggested preparation for this course.

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.

ENGN 1930Y. Social Enterprises.
This 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 PHY5 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.

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.

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.

Designing kinetic systems (i.e., systems requiring movement or motion) relies on both mechanical and electrical understanding. These systems include everything from mobile robots for rescue operation to electrically powered moving sculptures. Through a series of projects, students combine knowledge of electronic circuit design, sensors, actuators, motors, microcontrollers, control theory, and programming to build design interactive art and robotic systems. Projects culminate in the design of a creative robotic system that incorporates several principles learned in class. Programming experience is helpful but not required. Prerequisites: ENGN 0040 and (ENGN 0520 or ENGN 1230 or ENGN 1630 or hardware experience). Otherwise, seek instructor approval.

ENGN 1931J. Social Impact of Emerging Technologies – The Role of Scientists and Engineers.
The role of engineering sciences in an ever-changing technology-driven world. Students will develop basic working knowledge of selected contemporary technologies that help identify and forecast future prospects while discerning future disruptions. Emphasis on the importance of ethical and social responsibilities that technologists must shoulder in answering societal challenges and contributing to policy making and corporate leadership. How do we create beneficial technologies yet anticipate their potential social costs, such as workforce automation or overdependence on the internet? Will we give up brains as our last private space? Who will control the data / technology ecosystem that influences our decisions? Fall ENGN1931J/S01 16841 Th 4.00-6:30 (A. Nurmmoko)

Students study how materials are used in cell-based biological applications focusing on engineered tissues and translational applications. Hybrid materials can be designed to elicit specific cellular interactions, including cell adhesion, mechanosensing, biochemical signaling, and electrical conduction. Primary scientific literature provides examples of design principles as applied to natural and synthetic materials in cell-based assays, engineered tissues, and in vivo implantation. Students participate in class discussions of scientific literature, lead discussion through oral presentation and group engagement, and write literature summaries including a final project (either a primary research manuscript or literature review). Pre Requisites: Recommended: Physiology/Cell & Molecular Biology, Biomaterials/Materials Science.

ENGN 1931L. Biomedical Engineering Design and Innovation II.
This course is part two of the culmination "Capstone" of the biomedical engineering educational experience. The primary objective of this course is to recall and enhance design principles introduced through the engineering core curriculum and to apply this systematic set of engineering design skills to biomedical engineering projects. Student teams formed in the previous semester will continue develop a design project based on an unmet clinical need with a clinical advisor, gaining hands-on process experience and generating innovative solutions. For seniors only. Non-engineering concentrators should register for ENGN 0931L.

ENGN 1931M. Industrial Machine Vision.
This course will offer advanced undergraduate and master's students a practical introduction to industrial applications of machine vision and will provide theoretical, hands-on experience with automation and visual inspection technologies. Computer Vision, the automated analysis of images and video sequences, began as a research subject within computer science and engineering and has become an accepted technology with industrial applications. Current industry applications of machine vision: Electronics, metal, automotive, wood, plastics, paper, textiles, films, food manufacturing, biomedicine. Common functions: Recognition of features or components, guidance of assembly, robotic arms or vehicles, welding, dispensing; and inspection, measurement, detection of defects.

ENGN 1931N. Building Entrepreneurial Ecosystems for Economic Inclusion.
Enterprising ecosystems represent recent developments for fostering economic development as leaders globally aspire to build successful ecosystems in their cities and regions. These ecosystems are entrepreneurs in relationships of exchange and mutual reciprocity within the institutional and cultural environment of entrepreneur support organizations (ESO), infrastructures, and resources. This course will examine the emergence of entrepreneurial ecosystems in different cities and the roles, functions, and goals of ESOs. Students will visit local ESOs to learn about ecosystems and inclusive economic development.

This course explores all the energy forms, but will focus on energy sources from which the majority of "useful" energy originates at the present time. Basic heat transfer problems related to energy efficiency are presented. Rankine and Brayton power cycles are introduced. Cycle modifications supporting energy efficiency are explored. Carbon footprint calculations are illustrated. Traditional and cutting-edge technologies for carbon capture and storage presented. Emissions such as SOx, NOx, and PM and their capture technologies investigated. The Earth climate model examined. The course features three 1-page long scientific summary writings and the tour to the Manchester Street Power Station. Fall ENGN1931P/S01 16297 Th 10:30-11:50(13) (I. Kulaots)

ENGN 1931Q. Entrepreneurial Management in Adversity.
Companies get into trouble all the time -- making wrong products for the market, failing to meet sales quotas. This course examines actions a company must take in adverse conditions. There is never enough time to hire consultants, do research, hire new employees. Top Management must make decisions, often with insufficient data and alternative ‘sub-optimal’ options. Primary objectives are to understand analysis and rapid action when faced with adversity; identify the cause of adversity, building solutions to prevent recurrence or give management the skills to solve problems; and develop recommendations and action plans to ‘sell’ to the Board of Directors.
ENGN 1931R. The Chemistry of Environmental Pollution.
This course examines fundamental chemical aspects of pollutants and methods used to address pollution. We will consider pollution in air, water and soil media, and how pollution arises. Basic aspects of pollutant chemical partitioning will be explored. Examples of site investigation and the chemical tools used for that purpose will be discussed, along with risk assessment. Different ways of cleaning up contaminated sites will be examined, along with considering how mitigation and natural processes might represent options for addressing the particular pollution situation. Prerequisites are (MATH 0100, 0170, 0180, 0200, 0350 or 0190) and (CHEM 0100 or 0330). Fall ENGN1931FS01 17621 MWF 10:00-10:50(14) (E. Suuberg)

ENGN 1931T. Interfaces, Information and 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 CSCI 0040 or higher) would be very helpful.

ENGN 1932B. Engineering Practice.
This course will cover issues faced by engineers which can contribute to the success or failure of engineering projects. Practical solutions will be discussed along with successful and unsuccessful efforts to address these issues. Topics include: good and bad designs, ethical issues, failure analysis, role of research, factory and plant practices, supply chain management and technology diffusion. Additionally, discussion will involve human factors.
Course will be taught in a seminar mode, meeting once per week.
Enrollment capped at 15 students and limited to those in their Junior or Senior year.

Starting and running a venture is one of the most rewarding and frustrating endeavors a manager faces. While good ideas abound, the hallmark of the entrepreneur is the ability to translate ideas into action. This course is experiential, project-based, and designed to help entrepreneurs turn ideas into real ventures. Students should have already identified a problem whose solution may serve as the basis for a venture. Some may have embarked upon venture-building already. This course will help them work in a structured way, with supportive mentorship and content, to make significant progress on the venture and increase chances of success. Fall ENGN1931WS01 16546 TTh 2:30-3:50(12) (J. Clark)

ENGN 1931W. Selling & Sales Leadership in the Entrepreneurial Environment.
Is there any skill more important to entrepreneurs than sales? Startups only have two problems: sales and all else. The entrepreneur starts with a product or service and must convince an embryonic team to join a firm before there is a product, financing or customers; and convince investors the idea is sound, doable, and profitable; and convince customers to rely on a company with no track record. Sales skills are essential. Entrepreneurs sell an intangible and must make it feel immensely tangible. Until company/product become tangible, sales responsibility never stops. Entrepreneurs are key sales figures and face of the company. Fall ENGN1931WS01 18562 TTh 1:00-2:20(08) (H. Anderson)

ENGN 1931X. Instrumentation for Research: A Biomaterials/Materials Project Laboratory.
This course is designed to prepare students for research in biomaterials/materials science by focusing on a project that yields a testable product/device. Advanced equipment/instrumentation will be used to fabricate and evaluate materials required for each project and to test the performance of the product/device that uses these materials. Example projects that illustrate the course plan include building a microfluidic-based medical sensor or fabricating a polymer-based battery. These example projects will be performed in laboratory sections. Course will be taught in a seminar mode, meeting once per week. Assignment will provide hands-on practice using programmatic interfaces 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 CSCI 0040 or higher) would be very helpful.

ENGN 1931Z. Control Systems Engineering.
Control Systems is an Engineering discipline that applies control theory to analyze and design systems with desired response behavior. The objective of this course is to introduce the student to the topic of feedback control design with applications on many diverse systems. The course will cover the fundamentals of classical control theory such as modeling, simulation, stability, controller design and digital implementation. It will also address basic aspects of state-space and modern control theory. The course is open to all Engineering majors and will make use of existing simulation packages such as Matlab/Simulink.

ENGN 1932C. C2S Neurotech: From Concept to Startup- Translating Neurotechnology (NEUR 1930J).
Interested students must register for NEUR 1930J.

Engineers persistently aim to create new structures, machines, and devices to leverage physical principles to man’s advantage. Stemming from recent concerns over the environmental impact of technology and increased market competition, there is heightened focus on increasing efficiency. Therefore, future engineers must come up with designs that are not only functional but also optimal. The course will present the mathematical theory of engineering optimization. Review of optimization theory and techniques from calculus.

Independent Study in Engineering. Instructor permission required after submitting online proposal (https://docs.google.com/a/brown.edu/forms/d/e/1FAtpQLSxZxg19sKc7xrl9ca5jrz4Md_NqFy70hnS8aYYO77MhqV/viewform). 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 (https://docs.google.com/a/brown.edu/forms/d/e/1FAtpQLSxZxg19sKc7xrl9ca5jrz4Md_NqFy70hnS8aYYO77MhqV/viewform). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

ENGN 1931Y. Advanced Engineering Optimization.
Advanced Engineering Optimization. Prerequisites are (MATH 0100, 0170, 0180, 0200, 0350 or 0190) and (CHEM 0100 or 0330). Fall ENGN1931YS01 16546 TTh 2:30-3:50(12) (J. Clark)

Independent Study in Engineering. Instructor permission required after submitting online proposal (https://docs.google.com/a/brown.edu/forms/d/e/1FAtpQLSxZxg19sKc7xrl9ca5jrz4Md_NqFy70hnS8aYYO77MhqV/viewform). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

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Independent Study in Engineering. Instructor permission required after submitting online proposal (https://docs.google.com/a/brown.edu/forms/d/e/1FAtpQLSxZxg19sKc7xrl9ca5jrz4Md_NqFy70hnS8aYYO77MhqV/viewform). 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 (https://docs.google.com/a/brown.edu/forms/d/e/1FAtpQLSxZxg19sKc7xrl9ca5jrz4Md_NqFy70hnS8aYYO77MhqV/viewform). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

ENGN 1931Y. Control Systems Engineering.
Control Systems is an Engineering discipline that applies control theory to analyze and design systems with desired response behavior. The objective of this course is to introduce the student to the topic of feedback control design with applications on many diverse systems. The course will cover the fundamentals of classical control theory such as modeling, simulation, stability, controller design and digital implementation. It will also address basic aspects of state-space and modern control theory. The course is open to all Engineering majors and will make use of existing simulation packages such as Matlab/Simulink.
This course focuses on numerical solutions of common problems encountered in engineering and physical sciences, and provides both theoretical underpinnings and practical use of such methods, relying on physical problems from engineering and physical sciences wherever possible. This course covers: 1) Matrix operations, including linear algebra, eigenvalue problems, vector calculus, etc. 2) Solving physical equations numerically: converting physical governing equations into numerically solvable problems to user-defined accuracy, focusing primarily on numerical integration methodologies. 3) Advanced numerical methods: introductions to Bayesian statistics (via Markov chain / Monte Carlo), machine learning (simple regression / classification algorithms), principle component analysis, and design of experiments.

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.

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.

The primary objective of the course is to train students on tools, skills, and behaviors required for effective management of complex engineering, research, and business development projects. Although the course will be framed in the context of early-stage technology companies, the skills and principles will be applicable to businesses of any size and maturity. The course is organized around three actionable themes: project management, team management, and decision making.

ENGN 2130. Innovation and Technology Management.
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 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 also includes larger more established organizations.

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.

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.

ENGN 2150. 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.

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.

ENGN 2210. Continuum Mechanics.


ENGN 2240. Linear Elasticity.

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.

ENGN 2290. Plasticity.
Theory of the 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 for 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.


ENGN 2370A. Thin Films.
No description available.

ENGN 2370B. Topics in Solid and Structural Mechanics.
Devoted to one or more advanced topics in solid and structural mechanics not covered in detail by the regular courses, such as: numerical methods in solid mechanics, theory of optimal design, shell structures and instability, or other topics of interest to the staff or visitors.

ENGN 2380. Fracture Mechanics.

Theory of electron optics and principles of transmission electron microscopy, including dynamical theory of electron diffraction and image contrast. Applications to materials analysis including defect, boundary, and phase analysis. Analytical electron microscopy including convergent beam diffraction, energy dispersive x-ray analysis, and energy loss spectroscopy. Intensive laboratory exercises.

ENGN 2410. Thermodynamics of Materials.

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.

ENGN 2430. Deformation Behavior of Materials.
This course examines the fundamentals of elastic and plastic deformation of crystals. Topics include: Linear elasticity as it applies to isotropic and anisotropic materials; Hooke’s law is reduced for various levels of symmetry from triclinic to cubic symmetry; Various yield criteria and their relevance; Plasticity mechanisms through an introduction to dislocation theory. A description of dislocation core structure and Symmetry and quantifying stress fields, energies, line tension and force on a dislocation and between dislocations. Dislocation motion, their dissociation, interaction, intersections and consequences. In the context of the above topics, we rationalize the mechanical behavior of single and polycrystals.

ENGN 2450. Exchange Scholar Program.
Fall ENGN2450 S01 15477 TTh 1:00-2:20(08) (S. Kumar)

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 polycrystal plasticity, work-hardening, stress-corrosion, creep, fatigue, hardening mechanisms, etc.

ENGN 2450. Exchange Scholar Program.
Fall ENGN2450 S01 15477 1:00-2:20(08) (S. Kumar)

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 2502. 3D Photography.
In 3D Photography, cameras and lights are used to capture the shape and appearance of 3D objects represented as graphical models 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.

An introduction to the basics of linear, shift invariant systems and signals and doing real processing of signal on a digital computer. 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.

ENGN 2540. Audio and Speech Processing.
Signal-processing and machine-learning techniques for speech, music and other audio signals is the topic. The basics for speech production and hearing are introduced. PDES and simplified vocal-tract models are derived for speech and acoustic propagation models are described. LPC, DFT/cepstral audio analysis methods are discussed as well as the modern method for speech synthesis. Basic dynamic programming and hidden Markov modeling are introduced. Microphone-array methods are presented. Coding methods for speech and music are included. Real-time issues are considered. A project and presentation are important in grading. Offered every other year.

ENGN 2550. 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 primates visual pathways, edge-detection, segmentation, orientation-selectivity, relaxation-labeling, shading, texture, stereo, shape, object-recognition.

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.
Electronics 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.

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 2600 or equivalent.

This course is intended to provide an introduction to optical microscopy for engineering and science students. Topics ranging from basic brightfield and fluorescence microscopy to Nobel-prize winning advanced optical microscopy methods will be discussed. The course will also provide students with the opportunity to acquire hands-on training on various microscopy platforms including the confocal laser scanning microscope and the multiphoton microscope, as well as basic sample preparation.

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 2735. Vibration of Mechanical Systems.
This course will focus on the vibration characteristics of mechanical systems. Topics will include: analysis of free and forced single degree-of-freedom linear oscillators, vibration control and isolation, multiple degree-of-freedom and continuous systems, and introduction to nonlinear oscillations. Relevant analytical and numerical methods useful for modeling and analysis of vibrating systems will be discussed throughout. Students will be expected to do some numerical calculations on a computer.

Fall ENGN2530 S01 16324 MWF 11:00-11:50(16) (H. Silverman)

ENGN 2735. Vibration of Mechanical Systems.
This course will focus on the vibration characteristics of mechanical systems. Topics will include: analysis of free and forced single degree-of-freedom linear oscillators, vibration control and isolation, multiple degree-of-freedom and continuous systems, and introduction to nonlinear oscillations. Relevant analytical and numerical methods useful for modeling and analysis of vibrating systems will be discussed throughout. Students will be expected to do some numerical calculations on a computer.

Fall ENGN2735 S01 17399 TTh 9:00-10:20(02) (D. Harris)
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; 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 2770. Atomic Reaction Engineering. Topics include electronic structure calculations, molecular dynamics, potential energy surfaces, thermodynamic connections, scaling and free-energy relations, surface reactivity, rate theory, electrocatalytic concepts, and applications of machine-learning to atomistic calculations. Students will have flexibility to pursue research directions of interest through project- and literature-based work. All software employed in the course is open-source, so students can continue to use these tools without license after the course completes. This course is intended for graduate students or advanced undergraduates. A background in thermodynamics is required. Experience in quantum and statistical mechanics as well as computing is useful, but not necessary.

Fall ENGN2770 S01 16551 TTh 2:30-3:50(12) (A. Peterson)

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 16326 MWF 2:00-2:50(10) (J. Ault)

ENGN 2820. Fluid Mechanics II. Introduction to concepts basic to current fluid mechanics research. Hydrodynamic stability, the concept of average fluid mechanics, introduction to turbulence and to multiphase flow, wave motion, and topics in inviscid and compressible flow.

ENGN 2880A. Chemical Reaction Engineering. Elements of chemical rate processes; steady-state and transient behavior of continuous-flow chemical reactors; uniqueness, multiplicity, and stability in chemical reactor systems and individual catalyst particles; heterogeneous chemical reactor analysis focusing packed beds (continuous and discrete models) and fluidized beds (deterministic and stochastic models).

ENGN 2910A. Advanced Computer Architecture. This course focuses on advanced computer architecture concepts, including super-scalar 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.

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.

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 microscale 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 singleasperity 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.

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 mechanism, 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.

This course is relevant for graduate students interested in environmental pollution chemistry. Undergraduates need permission of the instructor to register.

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, and 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 2910O. Atomic 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,N#T) 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 1840 and 1600 are helpful, but not required.

ENGN 2910Q. Chemically Reacting Flow.
This course focuses on problems in chemical engineering that involve both transport and chemical reaction. The emphasis will be on numerical methods for practical problems. The students will learn to use the opensource code Cantera. Examples will draw from combustion chemistry, porous media, and electrochemistry.

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.

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; 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.

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.

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.

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.

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 2911P. Fate and Transport of Environmental Contaminants.
Physical, chemical and biological processes governing the fate and transport of contaminants in the environment. Topics to be covered include solute transport, sorption processes, mass transfer, non-aqueous phase liquid (NAPL) entrainment and dissolution, abiotic and biotic transformations. A portion of the course will involve the use of analytical and numerical models to assess the impact of coupled processes on contaminant fate and transport.

ENGN 2911R. Analytical Modeling for Biomechanical and Biomedical Systems.
Students will develop fundamental understanding of important statistical, physical and mathematical modeling methods for biomedical engineering applications. Topics covered will include factorial design and analysis of experiments, modeling of infectious disease spread and dynamics, drug delivery, and cell and tissue mechanics. Students will learn statistical methods, factorial design of experiments, transport models, numerical methods, nonlinear and time dependent response, soft material modeling and applications of these methods in the biomedical systems. Students will also gain experience in critical analysis of scientific literature and effective oral and written communication. Prerequisite: APMA 0330 or equivalent.

ENGN 2911T. Ultrafast Optical Phenomena.
This course covers the generation, propagation, and measurement of short laser pulses, of duration less than one picosecond. Concepts include mode locking, the effects of dispersion, optical pulse amplification, and time-domain non-linear optical phenomena. Intended as an introduction to ultrafast phenomena for graduate students or advanced undergraduates; a basic understanding of electromagnetic waves and of quantum mechanics is assumed.

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, FPGA 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, and design tools. We will in particular focus on accelerating key emerging algorithms in machine and deep learning. 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 both be discussed.

ENGN 2912A. Toxicity of Nanoparticles.
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 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 arise 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: ENGN 1630 and ENGN 1640 or equivalent experience in digital design.

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. 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 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 1622 and 1630, or instructor permission. Enrollment limited to 20.

ENGN 2912L. Two Phase Flows.
Introduction of two-phase flows. Flow maps. Conservation Equations. Motion of single particles, drops or bubbles. Bubble growth and collapse. Cavitation. Dusty gases. Granular flows. Sprays. The student who successfully completes this course will be able to understand the principles to two phase fluid mechanics; be able to start reading specialized literature of the subject; recognize the areas of active research; and develop research projects in this general area. Prerequisites: Advanced undergraduate fluid mechanics (e.g., ENGN 1860); graduate fluid mechanics course (e.g., ENGN 2810).

Inspired by Richard Feynman’s lectures in computation, this course explores how physical principles/limits have been shaping paradigms of computing, with a particular focus on quantum computing. Topics include but are not limited to: Physical limits of computing, coding and information theoretical foundations, reversible computing, with a particular focus on quantum computing. Open to Junior level and above.

ENGN 2912P. 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 2912Q. Coherence of Light in Nanoptics 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 2912R. 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 2912W. Two Phase Flows.
Introduction of two-phase flows. Flow maps. Conservation Equations. Two-phase homogeneous flows. Drift flux models. Interfacial dynamics. Motion of single particles, drops or bubbles. Bubble growth and collapse. Cavitation. Dusty gases. Granular flows. Sprays. The student who successfully completes this course will be able to understand the principles to two phase fluid mechanics; be able to start reading specialized literature of the subject; recognize the areas of active research; and develop research projects in this general area. Prerequisites: Advanced undergraduate fluid mechanics (e.g., ENGN 1860); graduate fluid mechanics course (e.g., ENGN 2810).

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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; fundamentals of toxicology, biological impacts of exposure and risk assessment; pollutant dispersion, transport and bioaccumulation; and remediation technologies. The overarching theme is the interactive role of life sciences, physical sciences, and social sciences in the development of solutions to manage or avoid the adverse human health impacts of legacy, current, and emerging technologies. Enrollment limited to 30.

ENGN 2920E. Theory of Heterogeneous Materials.
Heterogeneous materials appear in nature (polycrystals, wood, bone, blood), physical systems (un)stable colloidal suspensions) or in engineering applications (fiber-reinforced materials, reinforced rubber in tires). They usually exhibit remarkable physical properties superior to the properties of individual components. Despite being comprised at the microscopic length scale of multiple domains with different physical properties, these materials behave as homogeneous materials and can be assigned macroscopic (effective) physical material-like properties for practical purposes. The course will cover classical and recent analytical, numerical methods for computation of various physical properties (viscous/thermal/dielectric, viscoelastic, thermoelastic, piezoelectric, electrostrictive) of heterogeneous materials that exhibit (non)linear and/or coupled behaviors.

ENGN 2920G. Creating Economic and Social Value from Your Science or Engineering Research.
As a graduate student or undergraduate researcher, the primary output of your research is new knowledge and research publications. But is there a more direct way of creating value, through licensing and commercialization to a company, through creating products or services, or through the creation of a new venture? And how can we assess the potential social impact? We will together examine some currently emerging science to establish the methods. Thereafter you will examine the science and technology within your own research group in order to discover value, value that you may possibly be able to exploit. Students must be actively participating in research. Undergraduate students must also be undertaking research (instructor permission is required). Graduate students are requested to contact the instructor when registering.

Fall ENGN2920G S01 18500 Th 4:00-6:30 (A. Kingon)

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 2952J. Topics in Computing with Emerging Technologies (CSCI 2952J).
Interested students must register for CSCI 2952J.

Fall ENGN2952J S01 18548 Arranged "To Be Arranged"

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 15478 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 residency requirement and are continuing research on a full time basis.

Fall ENGN2990 S01 15479 Arranged "To Be Arranged"
Font Notice

This document should contain certain fonts with restrictive licenses. For this draft, substitutions were made using less legally restrictive fonts. Specifically:

Helvetica was used instead of Arial.

The editor may contact Leepfrog for a draft with the correct fonts in place.