Students who have taken Advanced Placement (AP) courses in high school and/or have shown proficiency through Advanced Placement examinations are often able to start at a higher level than suggested above and shown in the standard programs below. If a student has advanced placement credit (e.g., placing out of MATH 0190 or MATH 0200), it is quite common for them to enroll in 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 (Random Variables), APMA 1170 (Numerical Analysis), APMA 1210 (Operations Research), or APMA 1650 (Statistical Inference). Note that in addition to the above options, the student with advanced placement in calculus courses may choose to enroll early in APMA 0350 and APMA 0360 which are normally taken in the sophomore year (not all engineering concentrations require APMA 0360, so the choices should be guided by the concentration guidelines below).

Note: Students who completed APMA 0330 and/or APMA 0340 prior to academic year 2021-22 may count those courses as satisfying the APMA 0350 and/or APMA 0360 requirements.

The student with advanced placement credit for MATH 0190 or MATH 0200 also has the further option of replacing the math course with an advanced-level science course, subject to the approval of the Concentration Advisor.

Advanced Placement

Courses that have been taken at the secondary school level are typically only used for placement into the appropriate course level at Brown. The examples of how this can be done in mathematics are given above, and there are other instances (such as in selection of the appropriate introductory chemistry course) where AP credit is considered. It should be noted, however, that advanced placement credits cannot be used to substitute for any Engineering concentration requirements; they are instead used to ensure that students are placed into the correct level of courses.

Transfer Credits

Some students will also complete courses at other universities during the time they are Brown students (sometimes during summers while they are not in residence at Brown; sometimes during a junior semester abroad). 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). In addition to the general rules governing such transfers, there are specific rules governing courses that will be offered as satisfying Engineering concentration requirements.

If the course proposed for transfer credit is offered by another department at Brown (i.e., that it carries a course number that does not start with ENGN), then the equivalent of the course must be established by that other department. This is done by submitting a formal request through the ASK system (https://ask.brown.edu/transfer_credits/information/index).

Once this approval has been received from the other department, the student’s internal transcript will show the equivalence and the course in question can be shown in the Engineering concentration declaration as having been completed elsewhere. If the equivalence to a Brown course is not approved, then there may still be “unassigned credit” given for the course. In this case, the situation relative to how it does or does not count for concentration credit needs to be discussed with the Concentration Advisor. In rare cases, students may petition the Engineering Concentration Committee to use courses that do not have an equivalent offered at Brown in order 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.

If the student wishes to transfer a course taken outside of Brown that would normally carry an Engineering course number, the sequence is a bit different. First, the student needs to fill out an Engineering Transfer Credit Approval Request (see https://engineering.brown.edu/
undergraduate/concentrations/concentration-options/study-abroad (https://engineering.brown.edu/undergraduate/concentrations/concentration-options/study-abroad/). This routes the request to the relevant Brown Engineering faculty member for approval. Once this has been obtained, then transfer approval is requested through the ASK system, as described above. This process ensures that the transcript will capture the equivalence of the externally completed course.

Substitutions for Required Courses

Students may petition the Engineering Concentration Committee to substitute a course in place of a defined concentration 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 needed 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 Advisor without requiring a formal petition to the Concentration Committee. (For courses taken elsewhere, the credit must be officially transferred as described above.) Students wishing to make substitutions of a broader nature should consult their Concentration Advisor for assistance in drafting their petition to the Engineering Concentration Committee. Such petitions may be approved by a majority vote of the Committee.

Standard Program for the A.B. Degree

Please note that the A.B. degree program is not accredited by ABET. 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. 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 0030, ENGN 0080, ENGN 0090, ENGN 0930A, ENGN 0930C, ENGN 0930B, ENGN 0930C, ENGN 0930F, ENGN 1010, ENGN 1931Q, ENGN 1931W, ENGN 2110, ENGN 2120, ENGN 2130, ENGN 2140, ENGN 2150, ENGN 2160, ENGN 2180. 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 0200 and APMA 0350, as well as at least one college-level science course from the general areas of chemistry (except CHEM 0100), life sciences, physics, or geological sciences. A programming course is also recommended, but not required. The entire program is subject to approval by an Engineering Concentration Advisor and the Director of Undergraduate Programs in Engineering. Note: Students who completed APMA 0330 prior to academic year 2021-22 may count that course as satisfying the APMA 0350 requirement.

Standard Program 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 Sc.B. Concentrations (non-accredited):

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 advisor, 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 Sc.B. Engineering concentrations; (iii) a detailed description of any independent study courses used for concentration credit, signed by the faculty advisor 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 full-time professional experiences (or part-time experiences of equivalent total effort) doing work that is related to their concentration programs, totaling 2-6 months, whereby each internship must be at least one month in duration in cases where students choose to do more than one internship experience. Such work is normally done at a company, but may also be at a university under the supervision of a faculty member. Internships that take place between the end of the fall and the start of the spring semesters cannot be used to fulfill this requirement. 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 School of Engineering

The reflective essays are subject to the approval of the student’s Concentration Advisor.

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.

Degrees with Honors in Engineering

Honors are granted by the University to students whose work in a field of concentration has demonstrated superior quality and culminated in an "Honors Thesis of Distinction." Honors recipients in the School of Engineering must meet the following criteria: (1) Demonstrate a strong academic record (60% A's or "S with Distinction" in their concentration through the seventh semester); (2) Propose and execute an independent research project under the guidance of a faculty member; (3) Complete a written thesis to the satisfaction of the Honors Program Committee; (4) Give a scientific/technical presentation at the Undergraduate Research Symposium in the spring semester; and (5) Fulfill all deadlines for applying or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

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 objectives of the Brown University Chemical Engineering Sc.B. Program are to produce graduates who will: (1) apply their knowledge of engineering, science, mathematics, and liberal arts to successful careers and leadership roles in industry, government, or academia; (2) apply independent, critical, and integrative thinking to a broad range of complex, multidisciplinary problems, and effectively communicate their solutions to broad audiences of diverse backgrounds; and (3) show a lifelong commitment to technical approaches 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 Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0110</td>
<td>Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0101</td>
<td>Honors Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0102</td>
<td>Introduction to Engineering: Design</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0103</td>
<td>Dynamics and Vibrations</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0104</td>
<td>Principles of Chemical and Atomics Engineering</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0105</td>
<td>The Foundation of Living Systems</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0106</td>
<td>Materials Science</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0107</td>
<td>Electricity and Magnetism</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0108</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0109</td>
<td>Digital Computing Systems</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0110</td>
<td>Thermodynamics</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0111</td>
<td>Fluid Mechanics</td>
<td>1</td>
</tr>
<tr>
<td>CHEM 0320</td>
<td>Equilibrium, Rate, and Structure</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Single Variable Calculus, Part I (Physics/ Engineering)</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0100</td>
<td>Single Variable Calculus, Part II</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Multivariable Calculus (Physics/ Engineering)</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0180</td>
<td>Multivariable Calculus</td>
<td>1</td>
</tr>
<tr>
<td>MATH 0350</td>
<td>Multivariable Calculus With Theory</td>
<td>1</td>
</tr>
<tr>
<td>APMA 0350</td>
<td>Applied Ordinary Differential Equations</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 0360</td>
<td>Applied Partial Differential Equations</td>
<td>1</td>
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</table>

2. Upper-Level Chemical Engineering Curriculum

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
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<tr>
<td>ENGN 1110</td>
<td>Transport and Biotransport Processes</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1120</td>
<td>Reaction Kinetics and Reactor Design</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1130</td>
<td>Chemical Engineering Thermodynamics</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1710</td>
<td>Principles of Heat Transfer</td>
<td>1</td>
</tr>
<tr>
<td>CHEM 0350</td>
<td>Organic Chemistry I</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 1650</td>
<td>Statistical Inference I</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 1655</td>
<td>Honors Statistical Inference I</td>
<td>1</td>
</tr>
<tr>
<td>or CSCI 1450</td>
<td>Advanced Introduction to Probability for Computing and Data Science</td>
<td>1</td>
</tr>
</tbody>
</table>

3. Capstone Design Course

- ENGN 1140 Chemical Process Design: 1

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

Total Credits: 21

1 Students who completed APMA 0330 and/or APMA 0340 prior to AY2021-22 may count these as satisfying the APMA 0350 and/or APMA 0360 requirements.
2 ENGN 1120 and 1130 are only offered in alternate years.
3 An advanced chemistry course approved by Concentration Advisor; the courses listed have been preapproved for this requirement.
4 An advanced course in the natural sciences approved by the Concentration Advisor. For suggestions of acceptable courses that fulfill this requirement, please see the Concentration Advisor.

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 Program Educational Objectives (PEOs) of the CE undergraduate program strives to prepare graduates who: (1) will succeed as leaders in the computer engineering and technology industry and in research and development positions within industry and academia; (2) will work effectively in a range of roles to solve problems with global, economic, environmental and societal impacts; and (3) will pursue lifelong learning through advanced degrees and professional development opportunities throughout their chosen career. 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.

1. Core Courses:

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<td>ENGN 0030</td>
<td>Introduction to Engineering</td>
<td>1</td>
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<tr>
<td>or ENGN 0031</td>
<td>Honors Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0032</td>
<td>Introduction to Engineering: Design</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0040</td>
<td>Dynamics and Vibrations</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0050</td>
<td>Principles of Chemical and Atomics Engineering</td>
<td>1</td>
</tr>
<tr>
<td>or BIOL 0200</td>
<td>The Foundation of Living Systems</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0060</td>
<td>Materials Science</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0070</td>
<td>Electricity and Magnetism</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0080</td>
<td>Electrical Circuits and Signals</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0090</td>
<td>Digital Computing Systems</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0091</td>
<td>Thermodynamics</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 0100</td>
<td>Fluid Mechanics</td>
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<td>Equilibrium, Rate, and Structure</td>
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<tr>
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<td>or APMA 0360</td>
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</tbody>
</table>

2. Advanced Engineering or Natural Sciences elective course: 1

3. Honors Thesis of Distinction: 1

4. Concentration Advisor. For suggestions of acceptable courses that fulfill this requirement, please see the Concentration Advisor.

Total Credits: 21

1 Students who completed APMA 0330 and/or APMA 0340 prior to AY2021-22 may count these as satisfying the APMA 0350 and/or APMA 0360 requirements.
2 ENGN 1120 and 1130 are only offered in alternate years.
3 An advanced chemistry course approved by Concentration Advisor; the courses listed have been preapproved for this requirement.
4 An advanced course in the natural sciences approved by the Concentration Advisor. For suggestions of acceptable courses that fulfill this requirement, please see the Concentration Advisor.

Math 0190 Single Variable Calculus, Part II (Physics/ Engineering): 1

Total Credits: 21

1 Students who completed APMA 0330 and/or APMA 0340 prior to AY2021-22 may count these as satisfying the APMA 0350 and/or APMA 0360 requirements.
2 ENGN 1120 and 1130 are only offered in alternate years.
3 An advanced chemistry course approved by Concentration Advisor; the courses listed have been preapproved for this requirement.
4 An advanced course in the natural sciences approved by the Concentration Advisor. For suggestions of acceptable courses that fulfill this requirement, please see the Concentration Advisor.
MATH 0200  Multivariable Calculus (Physics/Engineering)  1
or MATH 0180  Multivariable Calculus  
or MATH 0350  Multivariable Calculus With Theory
CHEM 0330  Equilibrium, Rate, and Structure  1
or ENGN 0410  Materials Science
or NEUR 0010  The Brain: An Introduction to Neuroscience
APMA 0350  Applied Ordinary Differential Equations  1
or APMA 1170  Introduction to Computational Linear Algebra
or APMA 1710  Information Theory
or CSCI 0220  Introduction to Discrete Structures and Probability
or CSCI 1570  Design and Analysis of Algorithms
or MATH 1260  Complex Analysis

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

CSCI 0150  Introduction to Object-Oriented Programming and Computer Science

AND

CSCI 0200  Program Design with Data Structures and Algorithms

OR

CSCI 0170  Computer Science: An Integrated Introduction

AND

CSCI 0200  Program Design with Data Structures and Algorithms

OR

CSCI 0190  Accelerated Introduction to Computer Science (plus one additional CSCI course subject to Concentration Advisor approval)

2. Upper-Level Computer Engineering Curriculum:

ENGN 1570  Linear System Analysis  1
ENGN 1630  Digital Electronics Systems Design  1
ENGN 1640  Design of Computing Systems  1
MATH 0520  Linear Algebra  1
or MATH 0540  Linear Algebra With Theory

One advanced Computer Engineering foundations course:  1

ENGN 1580  Communication Systems
ENGN 1600  Design and Implementation of Digital Integrated Circuits
ENGN 1610  Image Understanding
ENGN 1620  Analysis and Design of Electronic Circuits
ENGN 2530  Digital Signal Processing

One advanced Computer Science course with significant systems programming:  1

CSCI 0330  Introduction to Computer Systems
or ENGN 0500  Digital Computing 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 Computer Engineering electives. At least one must be an ENGN course, and at least one must be a CSCI course. Note that some upper-level courses are not offered every year. Other 1000- or 2000-level ENGN and CSCI courses outside of the list below may also be approved by the Concentration Advisor if they have appropriate connections to Computer Engineering.

ENGN 1220  Neuroengineering
ENGN 1450  Properties and Processing of Electronic Materials
ENGN 1560  Introduction to Applied Electromagnetics
ENGN 1580  Communication Systems
ENGN 1590  Semiconductor Devices
ENGN 1600  Design and Implementation of Digital Integrated Circuits
ENGN 1610  Image Understanding
ENGN 1620  Analysis and Design of Electronic Circuits
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 1931M  Industrial Machine Vision
ENGN 1931Y  Control Systems Engineering
ENGN 2500  Medical Image Analysis
ENGN 2501  Digital Geometry Processing
ENGN 2502  3D Photography
ENGN 2520  Pattern Recognition and Machine Learning
ENGN 2530  Digital Signal Processing
ENGN 2540  Audio and Speech 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
ENGN 2912K  Mixed-Signal Electronic Design
ENGN 2920F  Sensors and Actuators for Real Systems
CSCI 0320  Introduction to Software Engineering
CSCI 1230  Introduction to Computer Graphics
CSCI 1270  Database Management Systems
CSCI 1380  Distributed Computer Systems
CSCI 1410  Artificial Intelligence
CSCI 1420  Machine Learning
CSCI 1430  Computer Vision
CSCI 1470  Deep Learning
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

3. Capstone Design  1

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
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.

Subject to approval by the Concentration Advisor, an independent study course (ENGN 1972/ENGN 1973) 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 https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/.

Electrical Engineering Track

The Electrical Engineering program is accredited by the Engineering Accreditation Commission of ABET: http://www.abet.org. The Program Educational Objectives (PEOs) of the Electrical Engineering Sc.B. Program are to prepare the graduates: (1) to leverage their knowledge of mathematics, science, engineering, and liberal arts to succeed as leaders in engineering and technology industries and in R&D positions in industry and academia; (2) to build broad knowledge and experience in interdisciplinary research and project management, and to apply critical thinking skills in developing and evaluating technological solutions addressing societal needs. 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:

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<td>Introduction to Engineering</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 0031</td>
<td>Honors Introduction to Engineering</td>
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<td>Introduction to Engineering: Design</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>
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<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 0500</td>
<td>Digital Computing Systems</td>
<td></td>
</tr>
<tr>
<td>or ENGN 0810</td>
<td>Fluid Mechanics</td>
<td></td>
</tr>
<tr>
<td>or CSCI 0200</td>
<td>Program Design with Data Structures and Algorithms</td>
<td></td>
</tr>
<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0520</td>
<td>Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>or MATH 0540</td>
<td>Linear Algebra With Theory</td>
<td></td>
</tr>
<tr>
<td>or APMA 0360</td>
<td>Applied Partial Differential Equations I</td>
<td></td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Single Variable Calculus, Part II (Physics/Engineering)</td>
<td>1</td>
</tr>
<tr>
<td>or MATH 0100</td>
<td>Single Variable Calculus, Part II</td>
<td></td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Multivariable Calculus (Physics/Engineering)</td>
<td></td>
</tr>
<tr>
<td>or MATH 0180</td>
<td>Multivariable Calculus</td>
<td></td>
</tr>
<tr>
<td>or MATH 0350</td>
<td>Multivariable Calculus With Theory</td>
<td></td>
</tr>
<tr>
<td>APMA 0350</td>
<td>Applied Ordinary Differential Equations</td>
<td>1</td>
</tr>
<tr>
<td>APMA 1650</td>
<td>Statistical Inference 1</td>
<td>1</td>
</tr>
<tr>
<td>or APMA 1710</td>
<td>Information Theory</td>
<td></td>
</tr>
<tr>
<td>or CSCI 1450</td>
<td>Advanced Introduction to Probability and Data Science</td>
<td></td>
</tr>
<tr>
<td>CSCI 0150</td>
<td>Introduction to Object-Oriented Programming and Computer Science</td>
<td>1</td>
</tr>
<tr>
<td>or CSCI 0111</td>
<td>Computing Foundations: Data</td>
<td></td>
</tr>
</tbody>
</table>

2. Upper-Level Electrical Engineering Curriculum

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1570</td>
<td>Linear System Analysis</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1620</td>
<td>Analysis and Design of Electronic Circuits</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1630</td>
<td>Digital Electronics Systems Design</td>
<td>1</td>
</tr>
<tr>
<td>PHYS 0790</td>
<td>Physics of Matter</td>
<td>1</td>
</tr>
<tr>
<td>or PHYS 1410</td>
<td>Quantum Mechanics A</td>
<td></td>
</tr>
</tbody>
</table>

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

At least one advanced Electrical Engineering foundations course:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1230</td>
<td>Instrumentation Design</td>
</tr>
<tr>
<td>ENGN 1580</td>
<td>Communication Systems</td>
</tr>
<tr>
<td>ENGN 1590</td>
<td>Semiconductor Devices</td>
</tr>
<tr>
<td>ENGN 1600</td>
<td>Design and Implementation of Digital Integrated Circuits</td>
</tr>
<tr>
<td>ENGN 1610</td>
<td>Image Understanding</td>
</tr>
<tr>
<td>ENGN 1640</td>
<td>Design of Computing Systems</td>
</tr>
</tbody>
</table>

Up to two other Electrical Engineering courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1220</td>
<td>Neuroengineering</td>
</tr>
<tr>
<td>ENGN 1560</td>
<td>Introduction to Applied Electromagnetics</td>
</tr>
<tr>
<td>ENGN 1650</td>
<td>Embedded Microprocessor Design</td>
</tr>
<tr>
<td>ENGN 1680</td>
<td>Design and Fabrication of Semiconductor Devices</td>
</tr>
<tr>
<td>ENGN 1690</td>
<td>Photonics Devices and Sensors</td>
</tr>
<tr>
<td>ENGN 1930B</td>
<td>Biomedical Optics</td>
</tr>
<tr>
<td>ENGN 1931A</td>
<td>Photovoltaics Engineering</td>
</tr>
<tr>
<td>ENGN 1931F</td>
<td>Introduction to Power Engineering</td>
</tr>
<tr>
<td>ENGN 1931I</td>
<td>Design of Robotic Systems</td>
</tr>
<tr>
<td>ENGN 1931Y</td>
<td>Control Systems Engineering</td>
</tr>
<tr>
<td>ENGN 1931Z</td>
<td>Interfaces, Information and Automation</td>
</tr>
</tbody>
</table>

Up to one interdisciplinary engineering science course:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLPS 1491</td>
<td>Neural Modeling Laboratory</td>
</tr>
<tr>
<td>CLPS 1520</td>
<td>Computational Vision</td>
</tr>
<tr>
<td>ENGN 1370</td>
<td>Advanced Engineering Mechanics</td>
</tr>
<tr>
<td>ENGN 1450</td>
<td>Properties and Processing of Electronic Materials</td>
</tr>
<tr>
<td>NEUR 2110</td>
<td>Statistical Neuroscience</td>
</tr>
<tr>
<td>PHYS 1420</td>
<td>Quantum Mechanics B</td>
</tr>
</tbody>
</table>

4. Capstone Design: At least one course from the following:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1650</td>
<td>Embedded Microprocessor Design</td>
</tr>
<tr>
<td>or ENGN 1000</td>
<td>Projects in Engineering Design I</td>
</tr>
<tr>
<td>or ENGN 1001</td>
<td>Projects in Engineering Design II</td>
</tr>
</tbody>
</table>

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

Total Credits: 21

1 Another APMA/MATH course, such as MATH 0520 or APMA 0360, can be used in consultation with the Concentration Advisor, provided ENGN 1580 is taken in the upper-level Electrical Engineering program.

2 ENGN 1931Z may replace CSCI 0150 or meet an upper-level elective requirement, but not both.

3 Other Electrical Engineering foundations courses can also be taken, as well as a 2000-level Electrical Engineering graduate course, such as ENGN 2500, ENGN 2520, ENGN 2530, ENGN 2560, ENGN 2912K, ENGN 2610.

4 Or CSCI course beyond CSCI 0200, subject to Concentration Advisor approval. CSCI 0200 cannot be used to fulfill two requirements.
Environmental Engineering Track

The Environmental Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. Within a few years of graduation, graduates of the Brown Environmental Engineering (EnvE) Program will: (1) Engage in continued learning through professional development, professional licensure, and service to the profession and society; (2) Achieve leadership positions or roles that advance environmental engineering practice; and (3) Pursue and successfully obtain an advanced graduate or professional degree in environmental engineering or a related discipline. 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/

1. Core Courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</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>or ENGN 0032</td>
<td>Introduction to Engineering: Design</td>
</tr>
<tr>
<td>ENGN 0040</td>
<td>Dynamics and Vibrations</td>
</tr>
<tr>
<td>ENGN 0410</td>
<td>Materials Science</td>
</tr>
<tr>
<td>or ENGN 1490</td>
<td>Biomaterials</td>
</tr>
<tr>
<td>ENGN 0490</td>
<td>Fundamentals of Environmental Engineering</td>
</tr>
<tr>
<td>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>or ENGN 0500</td>
<td>Digital Computing Systems</td>
</tr>
<tr>
<td>or 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>BIOL 0200</td>
<td>The Foundation of Living Systems</td>
</tr>
<tr>
<td>CHEM 0330</td>
<td>Equilibrium, Rate, and Structure</td>
</tr>
<tr>
<td>MATH 0190</td>
<td>Single Variable Calculus, Part II (Physics/Engineering)</td>
</tr>
<tr>
<td>or MATH 0100</td>
<td>Single Variable Calculus, Part II</td>
</tr>
<tr>
<td>MATH 0200</td>
<td>Multivariable Calculus (Physics/Engineering)</td>
</tr>
<tr>
<td>or MATH 0180</td>
<td>Multivariable Calculus</td>
</tr>
<tr>
<td>or MATH 0350</td>
<td>Multivariable Calculus With Theory</td>
</tr>
<tr>
<td>APMA 0350</td>
<td>Applied Ordinary Differential Equations</td>
</tr>
<tr>
<td>or APMA 0360</td>
<td>Applied Partial Differential Equations</td>
</tr>
<tr>
<td>APMA 1650</td>
<td>Statistical Inference I</td>
</tr>
<tr>
<td>or APMA 1655</td>
<td>Honors Statistical Inference I</td>
</tr>
<tr>
<td>2. Advanced Science Courses</td>
<td></td>
</tr>
<tr>
<td>EEPS 1370</td>
<td>Environmental Geochemistry</td>
</tr>
<tr>
<td>or EEPS 0850</td>
<td>Weather and Climate</td>
</tr>
<tr>
<td>or EEPS 1310</td>
<td>Global Water Cycle</td>
</tr>
</tbody>
</table>

5 Subject to approval by the Concentration Advisor, an independent study course (ENGN 1972/ENGN 1973) 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 https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/(https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/)

6 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/

Environmental Engineering Program

The Environmental Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The Program Educational Objectives PEOs of the Environmental Engineering Sc.B. Program are to are to prepare the graduates: (1) To build on the knowledge gained in their undergraduate program in terms of strong engineering fundamentals, a specific strength in materials engineering, advanced written and verbal communication, and societal awareness and engagement, as well as new knowledge learned in their first years of

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 0420</td>
<td>Principles of Biology</td>
</tr>
<tr>
<td>or BIOL 0480</td>
<td>Evolutionary Biology</td>
</tr>
<tr>
<td>or BIOL 0500</td>
<td>Cell and Molecular Biology</td>
</tr>
<tr>
<td>or BIOL 0800</td>
<td>Principles of Physiology</td>
</tr>
<tr>
<td>or BIOL 1470</td>
<td>Conservation Biology</td>
</tr>
</tbody>
</table>

3. Upper-Level Environmental Engineering Curriculum

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1340</td>
<td>Water Supply and Treatment Systems - Technology and Sustainability</td>
</tr>
</tbody>
</table>

4. Capstone Design

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</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 Students who completed APMA 0330 and/or APMA 0340 prior to AY2021-22 may count these as satisfying the APMA 0350 and/or APMA 0360 requirements.

2 Or any other advanced Engineering course approved by the Concentration Advisor.

3 Subject to approval by the Concentration Advisor, an independent study course (ENGN 1972/ENGN 1973) 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 https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/(https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/)

4 Students in Classes of 2022, 2023, and 2024 may satisfy this requirement with APMA 0650 if taken in Spring 2021 or earlier.

Materials Engineering Track

The Materials Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The Program Educational Objectives PEOs of the Materials Engineering Sc.B. Program are to are to prepare the graduates: (1) To build on the knowledge gained in their undergraduate program in terms of strong engineering fundamentals, a specific strength in materials engineering, advanced written and verbal communication, and societal awareness and engagement, as well as new knowledge learned in their first years of

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>or EEPS 1320</td>
<td>Introduction to Geographic Information Systems for Environmental Applications</td>
</tr>
<tr>
<td>or EEPS 1330</td>
<td>Global Environmental Remote Sensing</td>
</tr>
<tr>
<td>or EEPS 1430</td>
<td>Principles of Planetary Climate</td>
</tr>
<tr>
<td>or EEPS 1520</td>
<td>Ocean Circulation and Climate</td>
</tr>
<tr>
<td>or EEPS 1710</td>
<td>Remote Sensing of Earth and Planetary Surfaces</td>
</tr>
<tr>
<td>BIOL 0420</td>
<td>Principles of Ecology</td>
</tr>
<tr>
<td>or BIOL 0480</td>
<td>Evolutionary Biology</td>
</tr>
<tr>
<td>or BIOL 0500</td>
<td>Cell and Molecular Biology</td>
</tr>
<tr>
<td>or BIOL 0800</td>
<td>Principles of Physiology</td>
</tr>
<tr>
<td>or BIOL 1470</td>
<td>Conservation Biology</td>
</tr>
</tbody>
</table>

Plus four advanced engineering courses from the list below

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1110</td>
<td>Transport and Bioransport Processes</td>
</tr>
<tr>
<td>ENGN 1120</td>
<td>Reaction Kinetics and Reactor Design</td>
</tr>
<tr>
<td>ENGN 1130</td>
<td>Chemical Engineering Thermodynamics</td>
</tr>
<tr>
<td>ENGN 1342</td>
<td>Groundwater Flow and Transport</td>
</tr>
<tr>
<td>ENGN 1700</td>
<td>Fluid Mechanics of Aerospace and Energy Systems</td>
</tr>
<tr>
<td>ENGN 1710</td>
<td>Principles of Heat Transfer</td>
</tr>
<tr>
<td>ENGN 1860</td>
<td>Advanced Fluid Mechanics</td>
</tr>
<tr>
<td>ENGN 1931P</td>
<td>Energy and the Environment</td>
</tr>
<tr>
<td>ENGN 1930U</td>
<td>Renewable Energy Technologies</td>
</tr>
<tr>
<td>ENGN 1931R</td>
<td>The Chemistry of Environmental Pollution</td>
</tr>
<tr>
<td>ENGN 2911P</td>
<td>Fate and Transport of Environmental Contaminants</td>
</tr>
</tbody>
</table>

Or any other course approved by the Concentration Advisor.
employment or graduate school, to move toward positions of responsibility, leadership, and influence in the field; and (2) to be viewed as outstanding engineering leaders, whether in start-ups or multinational corporations or academia, in terms of technical competence and in their understanding of an engineer’s responsibility to society and to ethical behavior. Through this reputation they will be having a significant organizational influence in their work. 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:

- ENGN 0030 Introduction to Engineering
- or ENGN 0031 Honors Introduction to Engineering
- or ENGN 0032 Introduction to Engineering: Design
- ENGN 0040 Dynamics and Vibrations
- ENGN 0410 Materials Science
- ENGN 0510 Electricity and Magnetism
- ENGN 0520 Electrical Circuits and Signals
- ENGN 0720 Thermodynamics
- ENGN 0310 Mechanics of Solids and Structures
- or ENGN 0810 Fluid Mechanics
- CHEM 0330 Equilibrium, Rate, and Structure
- MATH 0190 Single Variable Calculus, Part II (Physics/Engineering)
- or MATH 0100 Single Variable Calculus, Part II
- MATH 0200 Multivariable Calculus (Physics/Engineering)
- or MATH 0180 Multivariable Calculus
- or MATH 0350 Multivariable Calculus With Theory
- APMA 0350 Applied Ordinary Differential Equations
- or APMA 0360 Applied Partial Differential Equations I
- or MATH 0520 Linear Algebra
- or APMA 1210 Operations Research: Deterministic Models
- or APMA 1650 Statistical Inference I
- CHEM 0350 Organic Chemistry I
- 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 ENGN 1230 Instrumentation Design
- or ENGN 1740 Computer Aided Visualization and Design
- or ENGN 1750 Advanced Mechanics of Solids
- or APMA 0160 Introduction to Scientific Computing

2. Upper-Level Materials Engineering Curriculum

- ENGN 1410 Physical Chemistry of Solids
- ENGN 1420 Kinetics Processes in Materials Science and Engineering
- ENGN 1440 Mechanical Properties of Materials
- PHYS 0790 Physics of Matter
- or CHEM 0350 Organic Chemistry I
- or CHEM 1140 Physical Chemistry: Quantum Chemistry
- Three of the following:
  - ENGN 1450 Properties and Processing of Electronic Materials
  - ENGN 1470 Composite Materials
  - ENGN 1475 Soft Materials
  - ENGN 1480 Metallic Materials
  - ENGN 1490 Biomaterials
- ENGN 1000 Projects in Engineering Design I

Mechanical Engineering Track

The Mechanical Engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The Program Educational Objectives of the Mechanical Engineering program are to prepare the graduates: (1) to pursue careers as creative and innovative mechanical engineers in industry or academia; (2) to advance the frontiers of their field; and (3) to discharge their offices in a professional and responsible manner. 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:

- ENGN 0030 Introduction to Engineering
- or ENGN 0031 Honors Introduction to Engineering
- or ENGN 0032 Introduction to Engineering: Design
- ENGN 0040 Dynamics and Vibrations
- ENGN 0310 Mechanics of Solids and Structures
- ENGN 0410 Materials Science
- ENGN 0510 Electricity and Magnetism
- ENGN 0520 Electrical Circuits and Signals
- ENGN 0720 Thermodynamics
- ENGN 0810 Fluid Mechanics
- CHEM 0330 Equilibrium, Rate, and Structure
- MATH 0190 Single Variable Calculus, Part II (Physics/Engineering)
- or MATH 0100 Single Variable Calculus, Part II
- MATH 0200 Multivariable Calculus (Physics/Engineering)
- or MATH 0180 Multivariable Calculus
- or MATH 0350 Multivariable Calculus With Theory
- APMA 0350 Applied Ordinary Differential Equations
- or APMA 0360 Applied Partial Differential Equations I
- or MATH 0520 Linear Algebra
- or APMA 1210 Operations Research: Deterministic Models
- or APMA 1650 Statistical Inference I
- CHEM 0350 Organic Chemistry I
- 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 Projects in Engineering Design II
- or ENGN 1930L Biomedical Engineering Design and Innovation

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

Total Credits: 21

1. Students who completed APMA 0330 and/or APMA 0340 prior to AY2021-22 may count these as satisfying the APMA 0350 and/or APMA 0360 requirements.

2. These courses are taken in either the junior or senior year. Note that ENGN 1450, ENGN 1470, ENGN 1475, and ENGN 1480 are typically offered in alternate years.

3. Subject to approval by the Concentration Advisor, an independent study course (ENGN 1972/ENGN 1973) 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 https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/

The School of Engineering
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 Fluid Mechanics of Aerospace and Energy Systems
  - ENGN 1710 Principles of Heat Transfer

Capstone: At least one course from the following must be taken in the final two semesters:
  - ENGN 1000 Projects in Engineering Design I
  - ENGN 1001 Projects in Engineering Design II
  - ENGN 1930M Industrial Design
  - ENGN 1931D Design of Mechanical Assemblies
  - 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

Robotics 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 Scientific Computing
  - 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
  - ENGN 1340 Water Supply and Treatment Systems - Technology and Sustainability
  - ENGN 1440 Mechanical Properties of Materials
  - ENGN 1470 Composite Materials
  - ENGN 1570 Linear System Analysis
  - ENGN 1931F Introduction to Power Engineering
  - 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 I
- 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

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1. ENGN 1490 may be substituted if taken in Sophomore year.
2. Students who completed APMA 0330 and/or APMA 0340 prior to AY 2021-22 may count these as satisfying the APMA 0350 and/or APMA 0360 requirements. 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 1972/ENGN 1973) 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 https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/ (https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/)
4. Other advanced alternative courses can be used with the approval of the Concentration Advisor.
5. Other non-introductory courses in physics, chemistry, neuroscience, geology, and biology are allowed.

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**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 0100 or MATH 0190. Students who begin in MATH 0200 can substitute an additional science, engineering or higher-level mathematics course for the 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:

- ENGN 0030 & ENGN 0040 Introduction to Engineering and Dynamics and Vibrations (ENGN 0031 may be substituted for ENGN 0030)
- PHYS 0050 & PHYS 0060 Foundations of Mechanics and Foundations of Electromagnetism and Modern Physics
- PHYS 0070 & PHYS 0160 Analytical Mechanics and Introduction to Relativity, Waves and Quantum Physics
- MATH 0190 Single Variable Calculus, Part II (Physics/Engineering)
- or MATH 0100 Single Variable Calculus, Part II
- MATH 0200 Multivariable Calculus (Physics/Engineering)
- or MATH 0180 Multivariable Calculus
- or MATH 0350 Multivariable Calculus With Theory

Select three additional higher-level math, applied math, or mathematical physics (PHYS 0720) courses.
- CSCI 0111 Computing Foundations: Data
or APMA 0160 Introduction to Scientific Computing
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

- ENGN 0510 Electricity and Magnetism 1
- ENGN 0720 Thermodynamics
- PHYS 0470 Electricity and Magnetism
- PHYS 1500 Introduction to Applied Electromagnetics
- PHYS 0510 Advanced Electromagnetic Theory
- PHYS 1500 Advanced Classical Mechanics
- PHYS 1500 Advanced Engineering Mechanics
- PHYS 1220 Quantum Mechanics A
- PHYS 1220 Quantum Mechanics B
- ENGN 1500 Thermodynamics and Statistical Mechanics
- ENGN 0720 Thermodynamics
- CHEM 1620 Analysis and Design of Electronic Circuits
- CHEM 0330 Equilibrium, Rate, and Structure
- ENGN 0310 Mechanics of Solids and Structures
- ENGN 0810 Fluid Mechanics
- PHYS 1600 Computational Physics
- ENGN 0410 Materials Science
- ENGN 0410 Photonics Devices and Sensors
- PHYS 0560 Experiments in Modern Physics
- PHYS 0560 Modern Physics Laboratory
- ENGN 1590 Semiconductor Devices

or an approved 2000-level engineering or physics course.

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

- PHYS 1900 Senior Conference Course
- ENGN 1970 Independent Studies in Engineering
- ENGN 1970 Independent Study in Engineering
- ENGN 1972 Independent Study in Engineering Design
- ENGN 1973 Independent Study in Engineering Design

* 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. Alumni of the Biomedical Engineering (BME) program will achieve one or more of these program educational objectives (PEOs) within five (5) years of graduation: (1) Serve society through work or advanced study in a broad range of fields including, but not limited to, medicine, healthcare, industry, government, and academia; (2) Apply their deeply creative and versatile biomedical engineering education to solve a broad spectrum of engineering and societal challenges; and (3) Contribute as role models, mentors, or leaders in their fields. 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

- ENGN 0030 Introduction to Engineering 1
- ENGN 0031 Honors Introduction to Engineering
- ENGN 0032 Introduction to Engineering: Design
- ENGN 0040 Dynamics and Vibrations
- ENGN 0051 Electricity and Magnetism
- ENGN 0052 Electrical Circuits and Signals
- ENGN 0720 Thermodynamics
- ENGN 0810 Fluid Mechanics
- CHEM 0330 Equilibrium, Rate, and Structure
- MATH 0190 Single Variable Calculus, Part II (Physics/Engineering)
- MATH 0100 Single Variable Calculus, Part II
- CHEM 0350 Organic Chemistry I
- MATH 0200 Multivariable Calculus (Physics/Engineering)
- MATH 0180 Multivariable Calculus
- MATH 0350 Multivariable Calculus With Theory
- APMA 0350 Applied Ordinary Differential Equations
- APMA 1650 Statistical Inference
- BIOL 0495 Statistical Analysis of Biological Data
- PHP 1510 Principles of Biostatistics and Data Analysis
- APMA 1655 Honors Statistical Inference I

#### 2. Upper Level Biomedical Engineering Curriculum

- ENGN 1110 Transport and Biotransport Processes
- ENGN 1210 Biomechanics
- ENGN 1230 Instrumentation Design
- ENGN 1490 Biomaterials
- BIOL 0800 Principles of Physiology

#### 3. Additional Biomedical Engineering Electives: Complete at least 3 courses from the following groups; other upper-level courses are subject to Concentration Advisor approval.

Select one or two of the following:

- CSCI 1810 Computational Molecular Biology
- CSCI 1820 Algorithmic Foundations of Computational Biology
- ENGN 0500 Digital Computing Systems
- ENGN 1220 Neuroengineering
- ENGN 1510 Nanoengineering and Nanomedicine
- ENGN 1520 Cardiovascular Engineering
- ENGN 1550 Recent Advances in Biomedical Engineering
- ENGN 1740 Computer Aided Visualization and Design
- ENGN 1930B Biomedical Optics
- ENGN 2625 Optical Microscopy: Fundamentals and Applications
- ENGN 2910S Cancer Nanotechnology
- ENGN 2911R Analytical Modeling for Biomechanical and Biomedical Systems
- ENGN 2912R Implantable Devices
- BIOL 1140 Tissue Engineering
## Certificate Requirements

**Core Courses:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 0900</td>
<td>Management of Industrial and Nonprofit Organizations</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 1010</td>
<td>The Entrepreneurial Process</td>
<td>1</td>
</tr>
</tbody>
</table>

**Elective Courses (choose two):**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 2080</td>
<td>Biochemistry</td>
<td></td>
</tr>
<tr>
<td>BIOL 0470</td>
<td>Genetics</td>
<td></td>
</tr>
<tr>
<td>BIOL 0500</td>
<td>Cell and Molecular Biology</td>
<td></td>
</tr>
<tr>
<td>BIOL 0510</td>
<td>Introductory Microbiology</td>
<td></td>
</tr>
<tr>
<td>BIOL 1090</td>
<td>Polymer Science for Biomaterials</td>
<td></td>
</tr>
<tr>
<td>BIOL 1100</td>
<td>Cell Physiology and Biophysics</td>
<td></td>
</tr>
<tr>
<td>BIOL 1555</td>
<td>Methods in Informatics and Data Science for Health</td>
<td></td>
</tr>
<tr>
<td>APMA 1070</td>
<td>Quantitative Models of Biological Systems</td>
<td></td>
</tr>
<tr>
<td>CHEM 0360</td>
<td>Organic Chemistry II</td>
<td></td>
</tr>
<tr>
<td>ENGN 2910G</td>
<td>Topics in Translational Research and Technologies</td>
<td></td>
</tr>
<tr>
<td>NEUR 1020</td>
<td>Principles of Neurobiology</td>
<td></td>
</tr>
<tr>
<td>NEUR 1440</td>
<td>Mechanisms and Meaning of Neural Dynamics</td>
<td></td>
</tr>
<tr>
<td>PHYS 1610</td>
<td>Biological Physics</td>
<td></td>
</tr>
<tr>
<td>BIOL 1810</td>
<td>21st Century Applications in Cell and Molecular Biology</td>
<td></td>
</tr>
</tbody>
</table>

**4. Capstone Design**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 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.

**Total Credits:** **21**

1. Students who completed APMA 0330 and/or APMA 0340 prior to AY 2021-22 may count these as satisfying the APMA 0350 and/or APMA 0360 requirements.

2. In some rare cases, Independent Study may be substituted, subject to Concentration Advisor approval.

## 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 real-world projects.

### 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>

### General Education Requirement

At least one or two more courses from:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 0510</td>
<td>Drug and Gene Delivery</td>
</tr>
<tr>
<td>BIOL 1100</td>
<td>Cell and Molecular Biology</td>
</tr>
<tr>
<td>BIOL 1555</td>
<td>Methods in Informatics and Data Science for Health</td>
</tr>
<tr>
<td>APMA 1070</td>
<td>Quantitative Models of Biological Systems</td>
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<tr>
<td>CHEM 0360</td>
<td>Organic Chemistry II</td>
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<td>Topics in Translational Research and Technologies</td>
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</tr>
<tr>
<td>BIOL 1810</td>
<td>21st Century Applications in Cell and Molecular Biology</td>
</tr>
</tbody>
</table>

### Total Credits: **21**

1. Students must complete their practicum project by the end of the sixth semester.

## Engineering Graduate Program

The School of Engineering directly offers graduate programs leading to Master of Science, Master of Science in Innovation Management and Entrepreneurship, Master of Arts in Design Engineering, and Doctor of Philosophy degrees.

In addition, the School of Engineering, in collaboration with the Division of Biology and Medicine, offers an interdisciplinary graduate program leading to the Master of Science and Doctor of Philosophy in Biomedical Engineering.

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

- Five-Year Sc.B./Sc.M.: [https://engineering.brown.edu/graduate/programs-guide/five-year-scb/scbscm-requirements](https://engineering.brown.edu/graduate/programs-guide/five-year-scb/scbscm-requirements)
The School of Engineering

Sc.M. in Engineering: https://engineering.brown.edu/graduate/programs-guide/scm-requirements
Brown-RISD Master of Arts in Design Engineering (MADE): https://design.engineering.brown.edu/
Ph.D. in Engineering: https://www.brown.edu/graduateprograms/engineering-phd

Master of Science (Thesis Option)

- Candidates must complete a coherent plan of study based in engineering or engineering science consisting of eight 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, Design) must be included.
- Three additional 2000-level engineering courses other than ENGN 2980 (Special Projects: Reading, Research, Design) must be included. Courses in engineering management (PRIME) are not acceptable for use as one of the 2000-level engineering courses.
- The remaining courses may include up to two ENGN 2980 class and up to three 1000-level Engineering or other approved science courses. 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 a 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.

Note: Students enrolled in a 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, 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 or other approved science 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 Studies 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 advisor.

Master of Science (Non-Thesis 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 |
| Three additional Engineering or approved science courses (not more than two 1000-level courses) | 3 |
| ENGN 2980 | Special Projects, Reading, Research and Design | 1 |
| Total Credits | 8 |

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.

| 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 ENGN courses (other than ENGN 2980) | 2 |
| Four additional Engineering or approved science courses (up to 3 may be 1000-level ENGN) | 4 |
| Total Credits | 8 |
• Three additional 2000-level engineering courses other than ENGN 2980 (Special Projects: Reading, Research, 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 or other approved science classes. Students should choose courses in consultation with the student’s advisor 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 Studies in the School of Engineering.

• For students in a 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 begin early to find a suitable internship (January is generally recommended). 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.

• Handshake at Brown (https://brown.joinhandshake.com/login/) (a password protected site) contains a database of jobs (not all are engineering related)

• 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 every November. Check the School of Engineering website (https://engineering.brown.edu/)'s event 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 alumni companies and titles, and is searchable with key words.

Complete 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 intend to seek CPT approval from OISSS). You must NEVER begin work before your internship is approved.

Master of Science (Non-Thesis Professional Track Option)

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 2020</td>
<td>1</td>
</tr>
<tr>
<td>or ENGN 2010</td>
<td>1</td>
</tr>
<tr>
<td>ENGN 2020</td>
<td>1</td>
</tr>
<tr>
<td>Two additional 2000-level Engineering courses (other than ENGN 2980)</td>
<td>2</td>
</tr>
</tbody>
</table>

Four additional Engineering or other approved science courses (up to three 1000-level Engineering courses)

Internship (paid or unpaid); must be approved by the School of Engineering

Total Credits

8

For more information on admission and program requirements for the Program in Innovation Management and Entrepreneurship (PRIME), please visit the following website: https://prime.brown.edu/

Other Sc.M. Requirements

International students must be full-time at all times throughout their academic program, with few exceptions which must be approved by the PRIME advisor.

Data-Enabled Computational Engineering and Science Graduate Program

The Data-Enabled Computational Engineering and Science (DECES) program targets students with recently obtained Bachelor of Science (BS) degrees in Engineering, Applied Mathematics, Computer Science, Physical Sciences, and related disciplines, who are interested in pursuing careers that involve advanced modeling and simulation in engineering and physical sciences. This program will also be of interest to research staff as well as working professionals whose success on the job depends on their ability to perform high-fidelity engineering simulations with data assimilation. Data-Enabled Computational Engineering and Science is an inherently interdisciplinary field requiring in-depth knowledge of advanced mathematics, numerical methods and their computer implementation, engineering sciences, and methods in the emerging field of Data Science. Given the composition of Brown's School of Engineering and Applied Math faculty, we are uniquely positioned to offer such a program using a combined Engineering and Applied Math graduate curriculum.

Program Requirements:

Two courses in Engineering, such as:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGN 1750</td>
<td>Advanced Mechanics of Solids</td>
</tr>
<tr>
<td>ENGN 2020</td>
<td>Mathematical Methods in Engineering and Physics II</td>
</tr>
<tr>
<td>ENGN 2210</td>
<td>Continuum Mechanics</td>
</tr>
<tr>
<td>ENGN 2220</td>
<td>Mechanics of Solids</td>
</tr>
<tr>
<td>ENGN 2340</td>
<td>Computational Methods in Structural Mechanics</td>
</tr>
<tr>
<td>ENGN 2410</td>
<td>Thermodynamics of Materials</td>
</tr>
<tr>
<td>ENGN 2520</td>
<td>Pattern Recognition and Machine Learning</td>
</tr>
<tr>
<td>ENGN 2810</td>
<td>Fluid Mechanics I</td>
</tr>
<tr>
<td>ENGN 2820</td>
<td>Fluid Mechanics II</td>
</tr>
<tr>
<td>ENGN 2930</td>
<td>Atomistic Modeling of Materials</td>
</tr>
</tbody>
</table>

Two courses in Applied Mathematics, such as:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>APMA 1690</td>
<td>Computational Probability and Statistics</td>
</tr>
<tr>
<td>APMA 2550</td>
<td>Numerical Solution of Partial Differential Equations I</td>
</tr>
<tr>
<td>APMA 2560</td>
<td>Numerical Solution of Partial Differential Equations II</td>
</tr>
<tr>
<td>APMA 2580A</td>
<td>Computational Fluid Dynamics</td>
</tr>
<tr>
<td>APMA 2630</td>
<td>Theory of Probability I</td>
</tr>
<tr>
<td>APMA 2822B</td>
<td>Introduction to Parallel Computing on Heterogeneous (CPU+GPU) Systems</td>
</tr>
</tbody>
</table>

Two courses in data science/high performance computing

Two additional courses. To ensure depth these may be taken in Engineering, Applied Mathematics, Data Science, or other relevant disciplines.

Total Credits

8
Please visit the following website: Program in Innovation Management and Entrepreneurship (PRIME), for more information on admission and program requirements for the program-and-schedule/). A program established internship with a PRIME-partnering company venture success. Students are given the opportunity to participate in decision making, globalization and management are provided to assure ideas to market. Core business skills in finance, strategy, marketing, learn how to develop embryonic ideas and execute how to bring these PRIME students experience the process of creating value from technology, management.

Design Engineering Graduate Program Master of Arts in Design Engineering (MADE)
The faculty and students of the MADE program have backgrounds in design and engineering. These combinations of vision with pragmatism, qualitative combined with quantitative, and users with technology, multiply our ability to assess conditions, envision alternatives, and produce effective solutions. Our work responds to practical challenges with creativity, analytical reasoning, research skills, and collaboration.

Core courses
ENGN 2170 Engineering Design: Measure and Make 2
ENGN 2171 Iterating with Intention 2
ENGN 2173 Design Engineering Communication 1
ENGN 2172 Integrate and Implement 2
Four additional elective credits. Students may take two 1 credit electives or one 2 credit elective in Fall and Spring at Brown or at the Rhode Island School of Design. Electives must be approved by the MADE Advisor. Note: A 3-credit RISD course = 1 Brown credit

Total Credits 11

For students in the MADE program, the approved course sequence is 2 Summer, 4 Fall, 5 Spring (1 of which takes place during Winter Session). Any deviation from this schedule can result in additional tuition and/or penalties.

Program in Innovation Management and Entrepreneurship Graduate Program Master of Science: Program in Innovation Management and Entrepreneurship (PRIME)
PRIME students experience the process of creating value from technology, learn how to develop embryonic ideas and execute how to bring these ideas to market. Core business skills in finance, strategy, marketing, decision making, globalization and management are provided to assure venture success. Students are given the opportunity to participate in a program established internship with a PRIME-partnering company during their studies. The PRIME program is offered either as a residential program or as an on-line program, with the same course requirements.

ENGN 2110 Business Engineering Fundamentals I 1
ENGN 2120 Business Engineering Fundamentals II 1
ENGN 2125 Engineering Management + Decision Making 1
ENGN 2150 Technology Entrepreneurship and Commercialization I 1
ENGN 2160 Technology Entrepreneurship and Commercialization II 1
ENGN 2180 Globalization Immersion Experience and Entrepreneurship Laboratory 1
Two 1000-level or above electives. Must be approved by the PRIME advisor.

Total Credits 8

For more information on admission and program requirements for the Program in Innovation Management and Entrepreneurship (PRIME), please visit the following website: https://prime.brown.edu/

Technology Leadership Graduate Program Requirements for the Master of Science in Technology Leadership

ENGN 2000 Effective Leadership: Theory and Practice 1
ENGN 2090 Tech Entrepreneurship 1
ENGN 2030 Persuasive Communication .5
ENGN 2060 Technology Leadership in a Changing Environment 1
ENGN 2700 Big Data and Machine Learning for Digital Enterprises 1
ENGN 2200 Economic Perspectives on Strategic Decision Making 1
ENGN 2050 Finance and Business Strategy 1
ENGN 2205 International Immersion .5
ENGN 2040 Leadership and Professional Development 5

Total Credits 10.5

Courses
ENGN 0020. Transforming Society-Technology and Choices for the Future. This course will address the impact that technology has on society, the central role of technology on many political issues, and the need for all educated individuals to understand basic technology and reach an informed opinion on a particular topic of national or international interest. The course will begin with a brief history of technology.

Spr ENGN0020 S01 25386 MWF 11:00-11:50(04) (J. Harry)
Spr ENGN0020 C01 25387 T 10:30-11:50 (J. Harry)
Spr ENGN0020 C02 25388 Th 10:30-11:50 (J. Harry)
Spr ENGN0020 C03 25389 T 2:30-3:50 (J. Harry)
Spr ENGN0020 C04 25390 Th 2:30-3:50 (J. Harry)

ENGN 0030. Introduction to Engineering. ENGN 0030 introduces students to the engineering profession and the important role engineers play in society. It provides the foundation for further study in engineering. The course begins with engineering design, followed by the analysis of static structures. Topics also include CAD, basic Matlab programming, professional ethics, and social responsibility. Led by an undergraduate mentor, students complete group design modules, which require an additional two hours of meeting time per week. We highly recommend that students have taken MATH 0100 or higher at Brown, or have completed the equivalent of AB calculus or higher in high school.

Fall ENGN0030 S01 16183 TTh 9:00-10:20(04) "To Be Arranged"
Fall ENGN0030 S02 16184 TTh 4:00-5:20(04) "To Be Arranged"

ENGN 0031. Honors Introduction to Engineering. ENGN 0031 introduces students to engineering and the important role engineers play in society, but with a greater emphasis on calculus-driven instruction and computational approaches using MATLAB and Mathematica. Technical topics include case studies across multiple engineering disciplines, static equilibrium, structural analysis, introductory robot kinematics, energy methods, CAD, professional ethics, and social responsibility. Students will also participate in group design projects which apply concepts from lectures. Students who complete ENGN 0031 may substitute an approved engineering or computer science course in place of CSCI 0111. Students are advised to concurrently enroll in MATH 0180/0190, or a higher MATH course.
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 (e.g., Matlab) 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 have a math background (AB calculus).

Fall ENGN0032 S01 16475 MWF 11:00-11:50(16) (M. Donohue)
Fall ENGN0032 C01 16481 T 6:40-8:00PM (M. Donohue)
Fall ENGN0032 C02 16482 M 8:30-9:50 (M. Donohue)
Fall ENGN0032 C03 16483 T 9:00-10:20 (M. Donohue)
Fall ENGN0032 C04 16484 Th 9:00-10:20 (M. Donohue)
Fall ENGN0032 C05 16485 W 8:30-9:50 (M. Donohue)
Fall ENGN0032 C06 17964 M 6:40-8:00PM (M. Donohue)
Fall ENGN0032 C07 17965 T 6:40-8:00PM (M. Donohue)
Fall ENGN0032 C08 17966 W 6:40-8:00PM (M. Donohue)

ENGN 0040. 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 0061. Undergraduate Teaching Assistant Apprenticeship: Full Credit.
Being an undergraduate TA is a learning and rewarding experience: Students get a deeper understanding of the course material and gain valuable management, mentoring, and social skills that they can take with them well into the future. Students taking this course must first be selected as an Undergraduate TA for an undergraduate Engineering course. Students can expect to work closely with the course instructor(s) on a variety of course-related topics, including preparation of material and development of assignments. A report on course development outcomes is expected as part of the course credit requirements.

Fall ENGN0061 S01 16599 Arranged (G. Palmore)
Spr ENGN0061 S01 25278 Arranged (G. Palmore)

ENGN 0062. Undergraduate Teaching Assistant Apprenticeship: Half Credit.
Being an undergraduate TA is a learning and rewarding experience: Students get a deeper understanding of the course material and gain valuable management, mentoring, and social skills that they can take with them well into the future. Students taking this course must first be selected as an Undergraduate TA for an undergraduate Engineering course. Students can expect to work closely with the course instructor(s) on a variety of course-related topics, including preparation of material and development of assignments. A report on course development outcomes is expected as part of the course credit requirements.

Fall ENGN0062 S01 16600 Arranged (G. Palmore)
Spr ENGN0062 S01 25278 Arranged (G. Palmore)

ENGN 0090. Management of Industrial and Nonprofit Organizations.
Exposes students to the concepts and techniques of management. Topics include marketing, strategy, finance, operations, organizational structure, and human relations. Guest lecturers describe aspects of actual organizations. Lectures and discussions.

Fall ENGN0090 S01 16601 TTh 1:00-2:20(06) (T. Chaltas)
Fall ENGN0090 S02 16602 TTh 2:30-3:50(12) (T. Chaltas)

ENGN 0110. Lean LaunchPad.
The Lean LaunchPad (LLP) is a 12-week program that focuses on building 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 models. 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.

ENGN 0120B. Crossing the Space Chasm Through Engineering Design.
Five decades of human activity in space have provided the world with instant global communications and positioning, human and robotic exploration of the moon, planets and sun, and a perspective of earth which informs and influences our relationship with our environment. Unlike other technical revolutions in 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 for adoption of innovation, we will work in groups to identify uses of space, and a plan for their implementations, that could help space become “every day”. Through the process of design, we will confront the technical, economic, societal and political barriers to acceptance of innovation and to making new technologies beneficial to a wider range of users. Enrollment limited to 18 first year students.

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 0150. Principles of Chemical and Atomicistic Engineering

This course introduces students to core concepts of chemical and molecular engineering. Students will learn to formulate, derive, and solve material and energy balances for chemical systems. Examples will be drawn from diverse application areas that are relevant to chemical engineering in the twenty-first century. These examples will emphasize how to break down complex problems into simpler components, how to derive the governing equations from first principles, and how to obtain the solution using numerical methods. Students will learn fundamentals of molecular modeling methods, and how atomicistic techniques can be applied to engineering problems. The course is appropriate for students concentrating in any field of engineering, or related fields such as chemistry, physics, or biology.

ENGN 0230. Surveying

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

ENGN 0260. Mechanical Technology

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

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 or ENGN 0031 or ENGN 0032.

ENGN 0490. Fundamentals of Environmental Engineering

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 16607 TTh 1:00-2:20(06) (L. Kulaots)

ENGN 0500. Digital Computing Systems

Computers are so ubiquitous in modern technology that it is important to build a solid understanding of how computing machines are designed. We will work where software and hardware intersect, and introduce digital logic design, finite state machines, stored-program CPUs, digital data types, assembly language programming, compiler concepts and the C language. We will design digital logic and program modern RISC microprocessors similar to those in cell phones. We encourage all freshmen and sophomores interested in computing, and we welcome students from all Brown concentrations. It is assumed that students have some prior exposure to basic computer programming concepts.

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, 0031, 0032 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 16492 MWF 10:00-10:50(14) (A. Zaslavsky)
Fall ENGN0510 C01 16493 Th 9:00-10:20 (R. Beresford)
Fall ENGN0510 C02 16494 T 1:00-2:20 (R. Beresford)
Fall ENGN0510 C03 16495 W 1:00-2:20 (R. Beresford)

ENGN 0520. Electrical Circuits and Signals

An introduction to electrical circuits and signals. Emphasizes the analysis and design of systems described by ordinary linear differential equations. The frequency domain is introduced early and stressed throughout. Other topics include circuit theorems, power transfer, transient analysis, Fourier series, Laplace transform, a brief intro to diodes and transistors, and a little control theory. There is a lecture on engineering ethics. Laboratories apply concepts to real problems in audio and controls. Lectures, recitation, and laboratory. Prerequisite: MATH 0180 or MATH 0200, courses may be taken concurrent to ENGN 0520.

Spring ENGN0520 S01 25211 MWF 10:00-10:50(03) (L. Larson)
Spring ENGN0520 C01 25212 T 9:00-10:20 (L. Larson)
Spring ENGN0520 C02 25213 T 1:00-2:20 (L. Larson)
Spring ENGN0520 C03 25214 Th 9:00-10:20 (L. Larson)
Spring ENGN0520 C04 25215 Th 1:00-2:20 (L. Larson)

ENGN 0720. Thermodynamics

An introduction to macroscopic thermodynamics and some of its engineering applications. Presents basic concepts related to equilibrium and the zeroth, first and second laws for both closed and open systems. Examples include analysis of engines, turbines, and other engineering cycles, phase equilibrium and separation processes, chemical reactions, surface phenomena, magnetic and dielectric materials. Lectures, recitations, and laboratory. Prerequisites: ENGN 0030 or ENGN 0040 or equivalent; ENGN 0410 or CHEM 0330. An understanding of intermediate calculus is recommended, such as MATH 0180 or MATH 0200.
Properties of fluids, dimensional analysis. Fluid statics, forces on
submerged surfaces, kinematics. Conservation equations. Frictionless
incompressible flows, Euler's equations, Bernoulli's equation: thrust, lift,
Laminar and turbulent boundary layers, flow separation. Steady one-
dimensional compressible flow. Sound, velocity, flow with area change,
normal shocks. Lectures, laboratory. Prerequisites: MATH 0180 or 0200,
ENGN 0040 or PHYS 0050 or PHY$S 0070, APMA 0330 or APMA 0350
(can be concurrent).
Fall ENGN0810 S01 16496 MWF 1:00-1:50(08) (D. Harris)
Fall ENGN0810 C01 16497 Th 9:00-9:50 (D. Harris)
Fall ENGN0810 C02 16498 Th 12:00-12:50 (M. Martinez
Wilhelmus)

This course introduces the study of the design, engineering, work, material
culture and history through the construction of a traditional workshop,
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.
Spr ENGN0900 S01 25375 TTh 1:00-2:20(08) (T. Chaltas)

ENGN 0930A. Appropriate Technology.
Our goal for this course is that you leave it with the ability to think and act
rationally and concretely on issues of technology and the human condition.
We will provide background on useful technologies (e.g. wind, solar
hydro), techniques to fabricate them, and an opportunity to explore the
obstacles to their implementation.
Spr ENGN0930A/S01 26489 MWF 1:00-1:50(06) 'To Be Arranged'

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,
iteration, iteration, woodworking, prototyping, CNC milling and laser cutting
– in addition to other strategies that enhance our creative processes - as
we establish a technical and conceptual foundation for the design and
fabrication of objects and experiences. Enrollment limited to 16. Instructor
permission required.
Spr ENGN0930C/S01 25499 MW 11:00-1:50 (I. Gonsher)

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. 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 0931L.
Spr ENGN0931L/S01 25894 MWF 11:00-11:50(04) (C. Kofron)

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 16610 M 3:00-5:30(03) (I. Gonsher)

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
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 have submitted a project proposal no later than October 1. Instructor
permission required.
Spr ENGN1001 S01 25498 M 3:00-5:30(13) (I. Gonsher)

ENGN 1010. The Entrepreneurial Process.
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 16611 TTh 10:30-11:50(03) (D. Warshay)
Fall ENGN1010 S02 16612 W 3:00-5:30(03) (F. Slutsky)
Fall ENGN1010 S03 16613 M 6:00-8:30PM(03) (J. Cohen)
Spr ENGN1010 S01 25376 TTh 10:30-11:50(09) (D. Warshay)
Spr ENGN1010 S02 25377 TTh 9:00-10:20(05) (H. Ansari)

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. Prerequisites: Junior level or higher standing; APMA
0330 or 0350.
Spr ENGN1110 S01 26197 TTh 1:00-2:20(08) (A. Shukia)

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.

Fall ENGN1130 S01 16790 MWF 11:00-11:50(16) (A. Peterson)

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.

Spr ENGN1140 S01 25378 TTh 6:40-8:00PM(18) (M. Wojtowicz)

ENGN 1150. Environmental Engineering Design. Capstone engineering design course for Environmental Engineering. The course will involve introducing students to environmental contamination scenarios, developing responses to that scenario, e.g. Developing methods to assess the extent of the problem, to designing actual remediation, or mitigation strategies to address the problem. Coursework relies on laboratory measurements, computer modeling or both. Emphasis on conducting realistic assessments of the threat to human and ecological receptors (including learning about any relevant regulations), an evaluation of strategies to minimize negative impacts and consideration of both the costs and timescales needed for implementing alternatives. Prerequisites: ENGN 0490, ENGN 0720, ENGN 0810.

Spr ENGN1150 S01 25379 TTh 9:00-10:20(02) (K. Pennell)

ENGN 1210. Biomechanics. Important foundations of continuum biomechanics, properties 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/devices will be taught. Students will learn physical basis, theory and applications of each of these topics for biomedical engineering applications. Muscle biomechanics, biomechanics of walking and running, and response of soft tissue and bone will be discussed.

Spr ENGN1210 S01 25369 TTh 2:30-3:50(11) (V. Srivastava)

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 0100 and ENGN 0510; or instructor permission, which may be provided after discussion with course faculty.

Spr ENGN1220 S01 25474 TTh 1:00-2:20(08) (A. Nurmikko)


Fall ENGN1230 S01 16618 MWF 10:00-10:50(14) (D. Borton)

ENGN 1300. Structural Analysis. Classical and modern methods of analysis for statically indeterminate 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.

Spr ENGN1300 S01 25367 TTh 1:00-2:20(08) (Y. Bazilevs)


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.

Spr ENGN1340 S01 25380 W 3:00-5:30(10) (K. Pennell)

ENGN 1342. Groundwater Flow and Transport. Students in this course will develop a fundamental understanding of groundwater flow and transport processes. They will derive and apply mathematical models used in aquifer evaluation, aquifer testing, regional flow assessment, and solute transport predictions. Students will be introduced to state-of-the-art groundwater flow and transport simulators. A major portion of the course will be devoted to a team project in which students will use available geologic, hydrologic, and geochemical data from a selected site to develop, implement, and apply an aquifer model to address a real-world subsurface contamination problem.

Fall ENGN1342 S01 16652 TTh 9:00-10:20(05) (L. Abriola)

ENGN 1350. Art Fluids Engineering. This course aims to use fluid flows to create art. During a series of lectures, students will participate in discussions in which a ‘fluid’ idea will be presented. A contrasting scientific/engineering and artistic analysis will be conducted in each of these lectures. The students will then identify a flow problem to create a piece of art: dynamic sculptures, paintings, videos or installations. The art pieces will be presented at the end of the semester and exhibited publically.

Spr ENGN1350 S01 25280 MWF 10:00-10:50(03) (R. Zenit)


Spr ENGN1370 S01 25370 TTh 2:30-3:50(11) (H. Kesari)

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, fluorescence and confocal microscopy). Prerequisites: CHEM 0330, CHEM 0350, ENGN 0040 and BIOL 0200. Enrollment limited to 40.

ENGN 1410. Physical Chemistry of Solids.
Application of physical chemistry and solid state chemistry to the structure and properties of engineering solids as used in solid state devices, ceramics, and metallurgy. Equilibrium and free energy of heterogeneous systems, thermodynamics of solutions, chemical kinetics, diffusion, catalysis and corrosion, solid state transformations. Case studies taken from industrial practice. Prerequisites: ENGN 0410, 0720.

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.

Begins 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.

ENGN 1470. Composite Materials.
A study of the structure and properties of nonmetallic materials such as glasses, ceramics, and polymers. The crystal structure of ceramics, and the noncrystalline networks and chains 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

This course is an introduction to soft materials, focusing on natural and synthetic polymers and composites. Students will learn fundamentals of polymer chemistry (synthetic approaches) and polymer physics (thermodynamics, diffusion, viscosity); methods for characterizing/analyzing the structure of polymers in solution and solid state, including laboratory exercises; and approaches to designing polymers with properties for different applications (actuation, 3D printing, robotics, drug delivery). Course focuses on design of soft materials for specific applications and includes reading and discussion of primary literature. The course will be taught at a level suitable for undergraduates in engineering and graduate students in engineering and related fields.

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. Recommended: 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.

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.
In this course, students will learn quantitative physiological function of the heart and vascular system, including cardiac biomechanics and vascular flow dynamics, through lectures and discussion of current scientific literature. A systems approach will integrate molecular biophysics, cell biology, tissue architecture, and organ-level function into a quantitative understanding of health and disease. Discussion topics will include cardiovascular devices, pre-clinical regenerative therapies, stem cell ethics, and clinical trials.

ENGN 1550. Recent Advances in Biomedical Engineering.
This course will cover the latest developments in biomedical engineering over a broad range of areas including drug delivery, regenerative medicine, immune engineering, and diagnostics. Applications discussed within these fields may include infectious disease technologies, women’s health, global health technologies, biomaterials, etc. Students will learn about recent developments in these fields in academia, government, and industry. This course is intended for engineering and science graduate students and undergraduates interested in gaining an appreciation for current applications of biomedical engineering. An emphasis will be placed on critical analysis of current technologies and scientific communication with diverse audiences. This course is meant for engineering and science graduate and undergraduate students that have completed CHEM 0330 (or equivalent) and MATH 0100 (or equivalent).

ENGN 1560. Introduction to Applied Electromagnetics.
A first course on electromagnetic waves and photonics. Topics to be covered include basic wave phenomena with an emphasis on geometric optics, the interaction of light with matter, scattering, and interference and diffraction effects. Also covered will be a selected number of more advanced topics including laser physics, nonlinear optics, transmission lines, and antennas.
ENGN 1570. Linear System Analysis. Analysis of discrete and continuous electrical signals and systems in both time and frequency domains. Modulation, sampling, spectral analysis, analog and digital filtering, Fourier, Laplace and z-transforms, the state-space approach, stability of linear systems. Prerequisite: ENGN 0520. Fall ENGN1570 S01 16624 MWF 1:00-5:00(08) (P. Felzenszwalb)

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. Spr ENGN1580 S01 25475 TTh 2:30-3:50(11) (C. Rose)

ENGN 1590. Semiconductor Devices. An introduction to semiconductor device physics and basic electronic properties of semiconductors, including junctions, heterojunctions and fundamental device building blocks. Current and proposed semiconductor devices: field effect transistors, bipolar transistors, quantum-effect devices, and optoelectronic devices. A brief fabrication lab will introduce fabrication in the cleanroom. Advanced topics, such as heterojunction bipolar transistors and silicon-on-insulator FETs, included in the graduate version. Spr ENGN1590 S01 25476 MWF 2:00-5:00(07) (A. Zaslavsky)

ENGN 1600. Design and Implementation of Digital Integrated Circuits. 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. Fall ENGN1610 S01 16657 W 3:00-5:30(10) (B. Kimia)

ENGN 1620. Analysis and Design of Electronic Circuits. Elementary device physics and circuit characteristics of semiconductor diodes, bipolar junction transistors (BJTs), and field effect transistors (FETs). Analysis and design of practical circuits using discrete semiconductor devices. Constraint on and techniques for linear integrated circuit (IC) design and the use of linear ICs as circuit building blocks. Laboratory. Prerequisites: ENGN 0510, 0520 or equivalent. Spr ENGN1620 S01 25477 MWF 2:00-5:00(07) "To Be Arranged"

ENGN 1630. Digital Electronics Systems Design. Fundamentals of digital logic design including: Boolean algebra, gates, truth tables, logic families, flip-flops, finite state machines, memory, and timing. More advanced topics include A-D conversion, binary arithmetic, CPU organization, programmable logic (CPLDs and FPGAs), and VHDL. Extensive laboratory requirement. Not open to first year students; permission required for sophomores. Fall ENGN1630 S01 16626 TTh 1:00-2:00(06) (S. Reda)

ENGN 1640. Design of Computing Systems. This course introduces the main concepts and techniques for designing computing systems. Topics covered include assembly language, instruction set design, pipelining, superscalar and VLIW processor design, memory subsystem design, and I/O interfacing. Laboratory topics include programmable logic devices, hardware definition languages, and implementation of a bootable version of the pipelined MIPS processor. Laboratory emphasizes design optimizations with respect to speed and area. Prerequisite: ENGN 1630 or passing of a quiz on basic digital logic concepts, or instructor permission. Spr ENGN1640 S01 25478 TTh 1:00-2:20(08) (S. Reda)

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. Fall ENGN1650 S01 16627 MWF 2:00-5:00(01) (H. Silverman)

ENGN 1670. Soft Matter. This course provides an introduction to soft matter: polymers, elastomers, liquid crystals, and colloids. Students in physics, engineering, chemistry, and applied mathematics may find this course useful. Familiarity with classical statistical mechanics (PH1530) is required. We will use scaling arguments and simple physical pictures as much as possible.

ENGN 1680. Design and Fabrication of Semiconductor Devices. Contemporary practice in the design and fabrication of semiconductor devices. The realization of basic electronic device functions on the semiconductor platform is a central theme in a coordinated lecture and laboratory course. Topics include 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.

ENGN 1700. Fluid Mechanics of Aerospace and Energy Systems. Advanced fluid mechanics focusing on the physics, concepts, theories, and models of aerodynamics, renewable energy, turbomachinery, and space propulsion. Topics will focus on airfoil and wing theory, wind and water turbines; laminar and turbulent boundary layers; sub- and supersonic aerodynamics. A brief introduction to rocket propulsion and advanced space propulsion. Lectures, labs, computation and design projects. Prerequisites: ENGN 0720 and ENGN 0810.

Fall ENGN1700 S01 16791 MWF 11:00-11:50(11) (M. Rodriguez)
This course explores the transfer of energy as heat. It starts with basic heat transfer problems involving thermal conduction, convection, and radiation. The steady heat transfer through composite walls and heat dissipated from extended surfaces (such as fins) are examined. Transient heat transfer and heat transfer between solids and fluids will be investigated, considering natural and forced convection heat transfer. Various heat exchanger types will be evaluated, however concentric double-pipe heat exchangers analyzed in detail. Radiant heat transfer, surface emissive power, real surface radiation; view factors for black and gray surfaces will be studied. The course includes two hands-on laboratory experiments which supplement the material covered in the class meetings. The course also includes recitation sessions devoted to using COMSOL. The course ends with a design team competition focused on the most "efficient and elegant" coffee cup. Prerequisite: ENGN 0720

ENGN 1720. Design of Thermal Engines.
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 1730. Lasers and Nonlinear Optics.
This is a second course on optics and photonics and is intended for juniors interested in more advanced topics in modern optics who have already completed ENGN1690. Topics to be covered include the fundamentals of laser operation, gain and gain saturation, resonators, single-mode and multi-mode lasers, and a selection of important laser examples. We will then discuss light-matter interactions in the nonlinear regime, relying on a classical or semi-classical treatment. Topics will include frequency conversion via mixing or parametric processes, and degenerate third-order self-induced effects. Time permitting, we will discuss some of the most recent breakthroughs in optically-driven nonlinear processes such as laser-induced fusion as well as the planned exascale laser systems currently under development.

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 or 0350.

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

ENGN 1800. 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?

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 Fall ENGN1930B001 18232 MWF 12:00-12:50(15) (J. Lee)

ENGN 1930D. Large Scale Engineering Design Project.
Provides a major design experience for civil, mechanical, and, with approval, environmental engineering students. This experience involves an open-ended design problem that requires teamwork and the integration of understanding developed in upper-level courses in the engineering concentrations. Intended for students in their senior year.

ENGN 1930F. Entrepreneurship and Good Work: Engineering Dreams.
In this course, students examine the concepts of creation, organization, promotion, management and risk of ownership, to wit: entrepreneurship. This is done in the context of ‘good work’. Using a combination of relevant case studies, readings, guest lectures and discussion, each participant builds a theory and framework to explore what defines innovative and meaningful engagement during one’s working years. Enrollment limited to 24. Written permission required.

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

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 ENGN1930L001 16609 MW 8:30-9:50(09) (A. Tripathi)

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

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

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

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

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

ENGN 1930S. Land Use and Built Environment: An Entrepreneurial View.
Through the use of readings, group discussions, students presentations and guest lectures, students examine and challenge the analytical and structural frameworks which underlie and support public and private land and use the urban and suburban built environments. Students build an understanding and theory of how social, political, governmental and economic forces interact with society’s present and future physical space needs.
ENGN 1930T. 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 with 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.
eThis course will combine reading, discussion, field work, and guest talks by practitioners and theorists to delve into the workings of a variety of social enterprise models. Prerequisites: Social Entrepreneurship (ENGN1930Q) or comparable experience and an existing relationship with a social enterprise.

ENGN 1930Z. Robot Design.

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

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

In this course, we will focus on capital formation, valuation, and understanding the implications of investment and financing decisions that firms make. By the end of this course, you will be able to: Describe the role and purpose of the corporation; Calculate a firm's/project's cost of capital; Evaluate corporate projects and make decisions on whether or not to pursue them; Determine a corporation's optimal capital structure; Analyze the role, applicability, and issuance process of various debt and equity securities; Undertake a comprehensive valuation of a firm or 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. A series of projects, students combine knowledge of electronic circuit design, sensors, actuators, motors, microcontrollers, control theory, and programming to build 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?

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 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.
Entrepreneurial 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.

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 recurrences 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 migration 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).

ENGN 1931S. Medical Physics.
Medical Physics is an applied branch of physics concerned with the application of concepts and methods to the diagnosis and treatment of human disease. It applies with medical electronics, bioengineering, and health physics. Students will become familiar with major texts and literature of medical physics and be exposed to imaging and treatment techniques and quality control procedures. Students will acquire physical and scientific background to pose questions and solve medical physics problems. Topics include: Imaging, imaging metrics, ionizing radiation, radiation safety, radioactivity, computed tomography, nuclear medicine, ultrasound, magnetic resonance imaging, and Radiation Therapy (delivery systems, treatment planning, brachytherapy, image guidance).

ENGN 1931T. Entrepreneurship Practicum: Starting, Running, and Scaling Ventures.
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 for success.

ENGN 1931V. C2S Neurotech: From Concept to Startup-Translating Neurotechnology (NEUR 1930J).
Interested students must register for NEUR 1930J.
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.

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 manufacture 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 examples require materials synthesis (polymerization or hydrothermal), materials characterization (SEM, X-ray diffraction), device fabrication (microfabrication, assembly under inert/sterile atmosphere), and product testing (biological assays, electrochemical methods). Student interests will determine other projects. Completion of Laboratory Safety and Hazardous Waste Training offered by EHS.

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 space-time 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 1931Z. 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.

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

ENGN 1932D. Qualitative Market Research for Entrepreneurs & Business Innovators.
A critical element of entrepreneurship, and indeed all new business development, is to be able to undertake insightful market research, including developing an ‘understanding’ of the customers of potential new products and services. This requires qualitative research methods, and in this course participants learn to utilize the most recent and effective methods. A feature of the course is that the curriculum also explores the academic origins of the methods, developed from the fields of sociology, anthropology, management, and industrial design. Participants undertake a meaningful market research project in teams or as individuals.

ENGN 1932M. Foundations of Internet Communication Systems.
This course focuses on the foundational technologies that are the cornerstones of the modern Internet. We start with basic concepts in the field of Communications: analog vs. digital, digital sampling, SNR and detection in transmission of information. We then discuss voice/video/data media, packetized media, point-to-point, multicast and broadcast networks, radio, digital telephony, streaming media, wireless networking, satellite communications and the ever-evolving configuration of the Internet. We look at core enabling technologies (e.g., fiber optics), the development of key SW constructs used in the Internet and the popular “SaaS” model that enables most of commerce and collaboration across today’s Internet. The course includes presentations by industry experts and field trips to technology leading companies.

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. Calculus of variations. Necessary and sufficient conditions for optimality. Bioinspired engineering: optimal designs found in nature. Projects involving design and fabrication of optimal engineering systems will be encouraged.

Independent Study in Engineering. Instructor permission required after submitting online proposal (https://docs.google.com/a/brown.edu/forms/d/e/1FAIpQLSeXzgX19sKcq7xrL9ca5jr44Md_NqFYe70hn5I8aYY077MhqA/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/1FAIpQLSeXzgX19sKcq7xrL9ca5jr44Md_NqFYe70hn5I8aYY077MhqA/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, with approved design content. Instructor and concentration advisor approval is required after submitting online proposal (https://docs.google.com/a/brown.edu/forms/d/e/1FAIpQLSeXzgX19sKcq7xrL9ca5jr44Md_NqFYe70hn5I8aYY077MhqA/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 1973. Independent Study in Engineering Design
Independent Study in Engineering, with approved design content. Instructor and concentration advisor approval is required after submitting online proposal (https://docs.google.com/a/brown.edu/forms/d/e/1FAIpQLSeZgX19sKcq7XrL9ca5jrz4Md_NqFYe70hn5IBaYyO77MhqAV/viewform). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

The goal of this course is to enable participants to forge their own model for effective leadership, applying principles revealed through the study of literature, history, philosophy, politics, and contemporary leadership theory. We will identify the knowledge and competencies required to develop a robust identity as a leader. The course will then explore how leadership and strategy intersect and examine how leaders engage followers to unite around shared purpose and vision. Finally, we will review the ethical implications of leadership actions within an international context and establish the practices necessary to avoid the pitfalls of toxic leadership.

An introduction to methods of mathematical analysis in physical science and engineering. This course focuses on analytical techniques in mathematics. It includes series solution for differential equations, Fourier series and Fourier transform for solving partial differential equations, analytical maximum and minimum problems, calculus of variations and complex functions, and complex calculus. Fall ENGN2010 S01 16499 MTh 7:10-8:30PM(02) (A. Zaki)

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. Spr ENGN2020 S01 25219 MTh 5:40-7:00 (A. Zaki)

ENGN 2030. Persuasive Communication.
This course will provide students with theory, practice opportunities and individualized coaching to help them improve their oral and written communication skills. Students will focus on persuasive communication, including verbal and nonverbal communication, the relationship between a presenter’s goal and the goals/perspectives of the audience, and the rhetorical elements of logos, ethos and pathos. Students will learn how to create compelling business presentations using data visualization to generate people’s attention and stimulate action. This course includes the practice of writing as a method for thinking and learning, which develops students’ capacity for reflection and awareness of one’s self and others.

ENGN 2040. Leadership and Professional Development.
This half credit course is a critical component of STL. All readings, assignments and in class activities are focused on the four areas essential for leadership development: self-awareness, understanding leadership theory, skill development and the application of learning to the work environment.

As a result of participating in this class, students will expand their knowledge of leadership theories, in particular adaptive leadership theory, strengthen the interpersonal skills associated with the effective use of authority and leadership and increase their awareness of their impact on others. They will be consistently challenged to apply this knowledge and skills to their work environment.

The goal of this course is to learn the fundamentals of financial accounting, investment decision-making, and business strategy. The course will cover basic accounting concepts, including revenue recognition, inventory, long-lived assets, present value, long-term liabilities, and financial statements. We will study how accounting information is used in forecasting, operating, and measuring an enterprise. The course will explore how managerial accounting concepts are used to develop budgets and evaluate results and how to implement short- and long-term corporate strategy. Finally, the course will examine how strategic management is formulated in a multi-faceted environment of social, political, economic, and legal entities.

This course examine factors that contribute to successful technology leadership in today’s fast-paced and ever-evolving environment. Students use case studies from a wide range of industries to learn about, and gain practical experience in, the issues that ultimately determine the success (or failure) of highly technical undertakings. The alignment of marketing, technology and project execution is examined in both its best case and worst-case implementation. Through the lens of organizational effectiveness, value creation, addressing market needs and meeting customer expectations, students examine best practices used to engage the array of stakeholders that are crucial to positive outcomes.

ENGN 2070. Unlocking Value Globally.
This 10-module required course focuses on innovation as a driver for creating value globally. The modules provide an opportunity to consider the foundations for innovation in existing firms as well as innovations that can lead to entrepreneurial opportunities. Students will develop the knowledge and skills to understand the drivers of innovation, the challenges of creating innovation at a global scale, and the various ways in which inclusion is an important consideration in the development and deployment of innovations. Students will have the opportunity to learn from case studies that focus on innovation successes as well as failures in various firms across different industries. With the advent of new technologies, students will also discuss the opportunities and challenges represented by AI, automation, IoT, and other emerging areas for innovation.

ENGN 2080. Emerging Technologies and Innovation Ecosystems.
Technological trends and marketplace drive marketing strategy for technology development and management. Technology leaders use innovative models with effective product management to serve market needs. The course provides examples and case studies from biotechnology, environmental and energy technologies, information and communications technologies, and nanotechnology to learn about and gain practical experience applying new innovation models; engaging the constellation of innovation stakeholders; fostering a culture of continuous innovation; leveraging innovation, science, and technology policies; protecting intellectual property; overseeing effective product management; responding to technology trends and trajectories; and understanding regulations and external factors that affect technology development.

ENGN 2090. Tech Entrepreneurship.
This 10-module elective course focuses on tech entrepreneurship and aims to provide students with the decision-making, leadership and critical-thinking skills required to launch and lead successful technology ventures. It will also prepare students to consider ethical, socio-cultural and political complexities in the context as they decide to adopt new, emergent and/or established technologies. Students considering their own ventures or becoming part of a start-up will benefit from this course as well as those who may be leading innovation efforts in their firms. Those considering investing in start-ups can also benefit from learning about the business models for technology-based start-ups.
ENGN 2095. Psychological Perspectives on Strategic Decision Making.
Leadership is a choice. That choice and the many others that you make determine your value to your organization, and determine the quality of your life. But decision making is hard because the world is full of uncertainty, conflict, complexity, and ignorance. This course will focus on how people make decisions, revealing some systematic errors and useful decision-making strategies. We will review topics in judgment and decision making, a field related to behavioral economics, that covers academic and applied topics and draws from disciplines including cognitive science, psychology, statistics, economics, and philosophy. The focus will be on using insights from the field to find ways to improve individual, professional, and societal decision making.

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 students in the ScM Prime program.

ENGN 2160. Technology Entrepreneurship and Commercialization II.
ENGN 2160 develops the knowledge of, and embeds the skills for, technology-based entrepreneurship. While ENGN 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. Enrollment limited to 30 graduate students in the ScM PRIME program.

ENGN 2170. Engineering Design: Measure and Make.
Measure and Make is a series of experiences that ask students to come to an understanding of a context/place/situation that enables them to "devise courses of action aimed at changing the current situation to a preferred one." We will develop appropriate methods for measuring and making meaning, plan courses of action, and execute some of those plans to test the effect.

ENGN 2171. Iterating with Intention.
The studio experience forms the core of MADE. It gives students the opportunity to practice deliberate design engineering with guidance, mentoring, and critique from experienced academics and practitioners. Three short fall projects are arranged so that, as students progress, the responsibility for content, organization, and outcomes shifts from the faculty to participants.

ENGN 2172. Integrate and Implement.
In this final studio, students embark on a semester-long project to collaboratively develop their proposal into a proven, credible product implementation plan. These group-based, research-driven design engineering projects serve to illuminate skills and professional ambitions. They become the basis for building portfolios and integrate prior components of the program into a coherent whole. To start, the previously completed project proposal is developed for execution. It is refined to include further details such as project planning, professional audience and advisor identification, and budgeting. The remaining self-directed process will go on to include client interactions, user and market research, collaborative practice, realization strategies, prototyping and testing, and methods to "tell the story" of how the artifacts developed fit in the world.
ENGN 2173. Design Engineering Communication.
Communication is a vital component of effective collaboration. In this 4-week course, students learn how the extended human-centered design process can apply and be implemented by graphical and language-based communication for different audiences. Beginning with exercises framing the challenge of identifying and engaging different audiences, students will consider the breadth of variety of design engineering audiences and their information consumption and dissemination behaviors. Identify, adapt, and create appropriate communication strategies for a variety of objectives and contexts, such as individual inquiry, eliciting feedback or engaging support. Students teach each other, bringing tools and approaches from their disciplinary homes to this shared endeavor. This studio transitions discussions of effective communication to drafting the Capstone Studio proposal. Initial drafts are used as the basis for learning; they are developed and transformed from detailed statements of interest to a group proposal for all participants.
Spr ENGN2173 S01  25284  Arranged (B. Altringer)

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. Enrollment limited to graduate students in the PRIME program.

ENGN 2200. Economic Perspectives on Strategic Decision Making.
This course will develop students' strategic thinking skills by providing a theoretical framework for modeling rational decision-making, with extensions to interactive decision-making (game theory); decision-making under uncertainty; and behavioral approaches to decision-making. The course will also study applications of the theory to profit maximization by individual firms under different market structures such as perfect competition and oligopoly.

ENGN 2205. International Immersion.
This course is designed to develop innovative global leaders who can more effectively manage international markets, customers, suppliers, government regulations, and other partners. It aims to help students develop those capacities using Europe as a great example by providing an opportunity to evaluate all aspects of the European innovation ecosystem and apply critical, comparative, analytic skills and develop cultural awareness through academic lectures, visits to companies and cultural field trips. Students will examine all aspects of the innovation ecosystem that is recognized in Europe as a leading technology contributor in the world.

ENGN 2210. Continuum Mechanics.
Fall ENGN2210 S01  16674  MWF  10:00-10:50(14) (H. Kesari)

Spr ENGN2220 S01  25368  MWF  10:00-10:50(03) (P. Guduru)

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.
Spr ENGN2290 S01  25366  MWF  2:00-2:50(07) (D. Henann)

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.

Fall ENGN2340 S01  16675  MW  4:30-5:50(03) (Y. Bazilevs)

Students in this course will develop a fundamental understanding of groundwater flow and transport processes. They will derive and apply mathematical models used in aquifer evaluation, aquifer testing, regional flow assessment, andolute transport predictions. Students will be introduced to state-of-the-art groundwater flow and transport simulators. A major portion of the course will be devoted to a team project in which students will use available geologic, hydrologic, and geochemical data from a selected site to develop, implement, and apply an aquifer model to address a real-world subsurface contamination problem.
Fall ENGN2342 S01  17208  TTh  9:00-10:20(05) (L. Abriola)
ENGN 2350. Data-Driven Design and Analysis of Structures and Materials.
This course provides introductory knowledge on data-driven design and analysis of structures and materials. This course will try to balance theory and practice, such that the students become capable of understanding and using the methods in new scenarios. The first half of the course focuses on introducing machine learning from a probabilistic perspective, providing the foundations to understand current machine learning methods. The second part of the course focuses on applying machine learning to different engineering problems in solid mechanics.
Fall ENGN2350 S01 18097 MWF 1:00-1:50(08) (M. Bessa)

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.
Spr ENGN2380 S01 25371 TTh 2:30-3:50(11) (K. Kim)

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.
Spr ENGN2400 S01 25372 MWF 10:00-10:50(03) (D. Paine)

ENGN 2410. Thermodynamics of Materials.
Fall ENGN2410 S01 16676 TTh 10:30-11:50(13) (B. Sheldon)

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 Peierls stress, 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 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.
Fall ENGN2440 S01 16933 MWF 10:00-10:50(14) (W. Curtin)

ENGN 2450. Exchange Scholar Program.
Fall ENGN2450 S01 18112 Arranged ’To Be Arranged’

ENGN 2490A. Crystal Structures and Crystallography.
The study and experimental analysis of solid structures from crystallography and crystal chemistry viewpoints. Electronic structure of the atom as related to core level chemical analysis techniques in material science, atomic arrangements in solids, form crystallography, crystal symmetry and symmetry of finite objects, and experimental techniques in x-ray diffraction.
Fall ENGN2490A S01 18379 TTh 9:00-10:20(05) (E. Chason)

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.
ENGN 2530. Digital Signal Processing. This course teaches the principles and the practical methods for processing real-world signals on a computer. The vital need to understand the effects from sampling and quantization is emphasized. Modern methods for designing digital filters and their use are introduced. Discrete-time and DFT properties, fast DFT algorithms (FFT), and spectral analysis are important further topics. Both stochastic and deterministic signals are differentiated and methods for processing them are introduced. Current methods for A/D conversion are explained. Mathematical homework, MATLAB reinforcement exercises, and an opened DSP task are all used to build competence.

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

ENGN 2570. Applied Stochastic Processes. 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 2590. Semiconductor Devices. An introduction to semiconductor device physics and basic electronic properties of semiconductors, including junctions, heterojunctions and fundamental device building blocks. Current and proposed semiconductor devices: field effect transistors, bipolar transistors, quantum-effect devices, and optoelectronic devices. A brief fabrication lab will introduce junction fabrication in the cleanroom. Advanced topics, such as heterojunction bipolar transistors and silicon-on-insulator FETs, included in the graduate version.

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

ENGN 2605. Image Understanding. Image Understanding is an Artificial Intelligence core technology that is experiencing explosive growth; it is central to medical image analysis, industrial inspection, image enhancement, indexing into pictorial and video databases, robotic vision, drone navigation and mapping, face recognition, image compression, etc. This graduate-level course covers theoretical underpinnings of this field and includes a series of practical MATLAB image processing projects. Knowledge of Fourier Transform is required; ENGN 1570 is recommended.

ENGN 2610. Physics of Solid State Devices. 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, ultrafast pulse generation, nonlinear processes of conduction electrons in semiconductors, bulk and surface polaritons. Prerequisite: ENGN 2600 or equivalent.

ENGN 2625. Optical Microscopy: Fundamentals and Applications. 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 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 2670. Soft Matter. This course provides an introduction to soft matter: polymers, elastomers, liquid crystals, and colloids. Students in physics, engineering, chemistry, and applied mathematics may find this course useful. Familiarity with classical statistical mechanics (PH1530) is required. We will use scaling arguments and simple physical pictures as much as possible.

ENGN 2700. Big Data and Machine Learning for Digital Enterprises. This course prepares students to lead big data and machine learning projects within their organization. This course will explore concepts and organizational structures necessary to drive high-visibility analytics projects from ideation to implementation using a Design Thinking framework. Students will explore concepts and case studies that explore medical use cases, B2C customer acquisition, eCommerce analytics, and measure product development & innovation ROI. Work will be completed both individually and in teams.
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.

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

ENGN 2750. Chemical Kinetics and Reactor Engineering.
This course focuses on the fundamentals of chemical kinetics with engineering applications. Topics include: quantum chemistry, statistical thermodynamics, and transition state theory; light versus loose transition states; the kinetics of gases, liquids, and surfaces; adsorption, desorption, surface diffusion; enzyme kinetics and biological processes; formation, solution, and interpretation of elementary mechanisms; global versus local sensitivity analysis; uncertainty quantification; and the coupling between fluid dynamics and chemical reactions.

ENGN 2760. Heat and Mass Transfer.

ENGN 2770. Atomistic 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.

ENGN 2790. Quantum Optics.
An introduction to the fundamental theory, mathematical formalism, and applications of quantum optics, the study of light and its interactions with matter at microscopic scales. Topics will include: an introduction to quantum mechanics using the bra-ket (or Dirac) notation, quantization of the electromagnetic fields, generation and detection of single photons, non-classical quantum states (single-mode states, Fock or number states, coherent and squeezed states), phasor diagrams, number-phase uncertainty, quantum theory of photoionization/photodetection, quantum description of mirrors, beam splitters, Mach-Zehnder interferometers, spontaneous emission and parametric downconversion, as well as interaction-free measurements. The course is intended for graduate and senior undergraduate students who would like to understand more advanced concepts in emerging fields, such as quantum computing. The material is self-contained, therefore students who do not have a deep background in quantum mechanics or optics will also be able to take the course proficiently.

ENGN 2800. Critical Challenge Project.
The Critical Challenge Project (CCP) is central to the Science & Technology Leadership program curriculum. The project identifies a critical organizational challenge, drawing from students’ own professional experience or future aspirations. Under the direction of an advisor, students analyze the critical challenge from multiple perspectives and through the insights developed throughout the program and create a comprehensive plan for addressing it. The course provides opportunities to students to apply personal leadership skills to business landscape which is adaptable to changing market needs, technological advances, and increased global competition. Successful CCPs present evidence of incorporation of learning accomplished through program courses, substantial research and stakeholder understanding and effective proposals for outcomes and solutions to be implemented in order to receive a grade of S and credit for the CCP course.

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.

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.

Students will learn to identify a fluid and develop the mathematical framework (differential equations) that describe compressible flow motion. We will then study fundamental flow characteristics for 1D linear and non-linear systems. Steady 1D problems, classical problems in compressible flow, will build your understanding of compressible behavior in more realistic applications. You will then learn to solve the Riemann problem for the Euler equations (unsteady 1D flow) using analysis and numerics. At the end of the course, we will survey advanced topics in multi-dimensional flows.

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: ENGN 0040, CSCI 0040 or equivalent programming ability. APMA 0330, APMA 0340 or equivalent.
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 (continuum and discrete models) and fluidized beds (deterministic and stochastic models).

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

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

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

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

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

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

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


ENGN 2910K. Cell Mechanics. Course is designed for students with a strong background that want to learn more about mathematical and mechanical descriptions of the cell and its functions. It will include an overview of cell biology emphasizing locomotion, mitosis (cell division), intracellular transport, cellular mechanotransduction, and biological material properties. The course will draw examples from recent theoretical and experimental research investigations, and teach quantitative tools commonly used by engineers in the field.

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

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, a group design project and a laboratory will acquaint students with the state-of-the-art in biosensors and applied microfluidics. The course is relevant to physicists, chemists, biologists and engineers.

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

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

ENGN 2910Q. 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 open-
source 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 (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 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) entrapment 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. Fall ENGN2911TS01 17120 MWF 9:00-9:50(09) (D. Mittleman)

ENGN 2911V. Advanced Topics in Computational Mechanics: Isogeometric Analysis, Meshfree Methods, and FSI. This course aims at exposing the graduate students in mechanics and beyond to the ideas and methods that go beyond classical Finite Element Methods (FEMs) for solid mechanics. The course will cover the following topics: 1. Isogeometric Analysis (IGA); 2. Meshfree methods, such as the Reproducing Kernel Particle Method (RKPM) or Peridynamics (PD); 3. Stabilized and variational multiscale (VMS) methods for fluid mechanics and Fluid--Structure Interaction (FSI). We will use Jupyter as the platform for testing the ideas presented in the lectures. Students will also be asked to read recent research papers in the field and make informal presentations.

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

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

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

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

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

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

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

ENGN 2912H. Interfacial Phenomena. This course is an introduction to mechanics of material interfaces. Particular cases considered are liquid surfaces (surface tension, contact line slip, electro-wetting, etc), lipid membranes, and thin elastic plates and shells. The course will cover detailed analyses of statics and dynamics of these interface. Classical and modern research papers related to these topics will form the motivation for the discussion. A unified treatment of these apparently disparate interfaces is presented to conclude the course. Prerequisites: ENGN 2010, 2020, 2210, or 2810.
ENGN 2912I. Selected Topics in Physics of Locomotion (PHYS 2610E).
Interested students must register for PHYS 2610E.

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

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

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

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

ENGN 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 2912T. Experimental Fluid Mechanics.

ENGN 2912U. Coordinated Mobile Robotics.
Mobile robotics has made a large impact in our lives, from how we satisfy our consumerism to how we fight wars. Thousands of warehouse robots autonomously zip around each other in a highly structured and specialized environment that makes coordination look easy, while military robots are often teleoperated by more than one person, making coordination difficult. Moving beyond highly controlled scenarios presents many challenges. Most importantly, mobile robots will interact in complex environments with other robots and people. How can we ensure robots safely do what we want them to do? What are the ethical ramifications of multirobot systems? In this course, we study the past, present, and future of coordinated mobile robotics, including a discussion of ethics. The majority of this course is a seminar-style survey of issues and approaches for control and coordination in multi-robot systems.

ENGN 2912V. Deep Learning for Scientists and Engineers.
This course introduces concepts and implementation of deep learning techniques for computational science and engineering problems to first or second year graduate students. This course entails various methods, including theory and implementation of deep learning techniques to solve a broad range of problems using scientific machine learning. Lectures and tutorials on Python, Tensorflow and PyTorch are also included. Students will understand the underlying theory and mathematics of deep learning; analyze and synthesize data in order to model physical, chemical, biological, and engineering systems; and apply physics-informed neural networks and neural operators to model and simulate multiphysics systems. Undergraduate students who want to enroll in this course should request an override through Courses@Brown.

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).

ENGN 2920A. Complex Fluids: Non Newtonian Fluid Mechanics.
Introduces the treatment of non Newtonian liquids in flow. A review of classical rheological models will be discussed in detail. The course will focus on effects of non Newtonian behavior on the flow of these materials. The intended audience is graduate students in Engineering, Physics, Chemistry, and Applied Mathematics. Prerequisite: We will use material from ENGN 2010/2020, such as differential equations, Fourier and Laplace transforms, elementary differential geometry, basic probability, vector calculus. A graduate course on fluid mechanics is required (ENGN2810).

This course introduces the students to the mechanics of battery materials and some of the current research problems. It will consist of a series of lectures by experts from academia and industry, which will cover the state of the art in lithium ion batteries, the role of mechanics in advancing the field, experimental studies, continuum modeling, ab initio modeling and practical design issues. There will be approximately one lecture each week (150 min); each lecture will focus on a specific aspect of battery materials, giving an in-depth treatment of scientific problems, the current state of understanding and future challenges.
ENGN 2920D. Environmental Technologies and Human Health.
This course explores interdisciplinary approaches to environmental safety and health drawing from Brown University faculty and other affiliated experts. Topics include history of environmental regulation and waste management; origin and chemistry of pollutants; 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.

This course is being introduced in Spring 2020 as a course specifically aimed toward ScM students, interested advanced undergraduates, and curious PhD students. The idea is to introduce some of the input and output components used in embedded systems, drones, robots, etc. This includes circuit analysis of analog sensors, estimation theory, including Kalman Filtering, to overcome noise inherent in all such systems, the discussion of some modern digital sensors, controlling the latest actuators including ways to control brushless DC motors. There is a lab component in the course.

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.

ENGN 2920H. Materials and Interfaces for Energy Storage Devices.
This is an introductory course that combines materials science and electrochemistry, emphasizing thermodynamics, charge transfer kinetics, interface structures, and ionic mass transport mechanisms in both liquid and solid materials. This course integrates the atomistic point of view with the macroscopic concepts in electrochemistry and energy storage devices. Examples of various battery and fuel cell technologies will be presented. An emphasis is placed on mechanistic understanding, quantitative analysis, and mathematical models of electrochemical systems. The course is intended to support graduate students conducting research involving electrochemical technologies.

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

ENGN 2970. Preliminary Examination Preparation.
For graduate students who have met the residency requirement and are paying the registration fee to continue active enrollment while preparing for a preliminary examination.

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.

ENGN 2991. Characterizing Nanomaterial Structure.
Characterizing nanomaterial structure is challenging as it requires multiple methods drawn from disciplines ranging from materials engineering to colloidal chemistry. This class will present analysis tools and will focus on their specific application to nanostructures, specifically those prepared via solution-phase chemistry. Material will be structured into four modules on (a) dimensions and morphology (b) internal structure (c) surface chemistry and (d) molecular analysis. Case studies will illustrate best practices for analyzing and reporting characterization data. This course provides students an opportunity to compare different methodologies as well as select not just sufficient, but appropriate, tools for a nanomaterial analysis problem.