The School of Engineering

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

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

The School of Engineering offers courses and programs leading to the Bachelor of Science (Sc.B.), the Bachelor of Arts (A.B.), the Master of Science (Sc.M.), the Master of Arts (A.M.), and the Doctor of Philosophy (Ph.D.).

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-scbscm-requirements (https://engineering.brown.edu/graduate/programs-guide/five-year-scbscm-requirements/)

Sc.M. in Biomedical Engineering: https://www.brown.edu/academics/ibeam/academics/graduate-program/master-science-scm-programs/scm-program-overviews

Sc.M. in Chemical Engineering: https://engineering.brown.edu/graduate/programs-guide/scm-requirements (https://engineering.brown.edu/graduate/programs-guide/scm-requirements/)

Sc.M. in Environmental Engineering: https://engineering.brown.edu/graduate/programs-guide/scm-requirements (https://engineering.brown.edu/graduate/programs-guide/scm-requirements/)

Sc.M. in Electrical and Computer Engineering: https://engineering.brown.edu/graduate/programs-guide/scm-requirements (https://engineering.brown.edu/graduate/programs-guide/scm-requirements/)

Sc.M. in Materials Science and Engineering: https://engineering.brown.edu/graduate/programs-guide/scm-requirements (https://engineering.brown.edu/graduate/programs-guide/scm-requirements/)

Sc.M. in Applied Mechanics and Mechanical Engineering: https://engineering.brown.edu/graduate/programs-guide/scm-requirements (https://engineering.brown.edu/graduate/programs-guide/scm-requirements/)

Sc.M. in Program in Innovation Management and Entrepreneurship (PRIME): https://prime.brown.edu/

Brown-RISD Master of Arts in Design Engineering (MADE): https://design.engineering.brown.edu/

Ph.D. in Biomedical Engineering: https://www.brown.edu/academics/ibeam/academics/graduate-program/phd-program/phd-program-overview (https://www.brown.edu/academics/ibeam/academics/graduate-program/phd-program/phd-program-overview/)

Ph.D. in Engineering: https://www.brown.edu/graduateprograms/engineering-phd (https://www.brown.edu/graduateprograms/engineering-phd/)

For additional information, please visit the School's website at: https://engineering.brown.edu/

Engineering Concentration Requirements

Engineers make decisions, by collecting and analyzing data; using scientific principles to formulate analytical models of a process; and predicting the outcome of candidate solutions to a problem. They use their creativity to identify innovative solutions to challenging problems. These skills are valuable not only in technical careers, but also in fields such as public service, environmental policy, architecture, teaching, technology management, finance, entrepreneurship or patent law. A foundation in engineering will help prepare you for the future, regardless of your aspirations. The School of Engineering offers the Engineering A.B. degree to enable students to combine a rigorous and interdisciplinary foundation in engineering with the diverse opportunities provided by Brown's liberal arts curriculum. With only 11 required courses, it has the greatest flexibility of all of the School's undergraduate degree programs.

Please note that all students concentrating in Engineering need to file a concentration declaration using the University's ASK advising system. This declaration must be first reviewed by the relevant Concentration Advisor and then approved by the Director of Undergraduate Studies after assuring compliance with all relevant program and accreditation requirements.

Mathematics Requirements

As mathematics is a cornerstone of all engineering programs, significant attention is given to early preparation in mathematics in engineering concentrations. It is recognized that students entering Brown will have different levels of mathematics preparation, and the following is offered as general guidance, though the actual choices of courses should be made in consultation with an exploratory advisor. MATH 0190 (or MATH 0100), followed by MATH 0200 (or MATH 0180) is the preferred sequence of courses to be taken in the freshman year. MATH 0100 and MATH 0180 offer content like that in MATH 0190 and MATH 0200, respectively, but the latter courses are highly recommended for future engineering students because they offer more examples of relevance to the field. Students who would prefer, or require, a more introductory level calculus course may start the sequence with MATH 0090. They may then take MATH 0200 (or MATH 0180) in the subsequent semester and in that case, would receive engineering concentration credit equivalent to that which they would have received having taken MATH 0190 and MATH 0200. However, students who find that the step up from MATH 0090 to MATH 0200 is too challenging, have a choice to take MATH 0190 (or MATH 0100) upon completion of MATH 0090, but in this case, MATH 0090 would not carry engineering concentration credit and the student would then need to take MATH 0200 (or MATH 0180) in the sophomore year.

Students who have taken Advanced Placement (AP) calculus courses in high school and/or have shown proficiency through AP examinations may start the calculus sequence at a higher level than that suggested above. If a student has AP credit and accepts to use it, it then allows the student to place out of MATH 0190 (or MATH 0100). These students should enroll in the appropriate higher-level math course, e.g., MATH 0200 (or MATH 0180) or possibly MATH 0350 (a more theoretical course that covers similar material). Although it is impossible to place out of MATH 0200 or MATH 0350 with AP credit, we recognize that some students enter with an even higher level of preparation. Those students are advised to enroll in MATH 0520 (Linear Algebra), or MATH 0540 (Honors Linear Algebra), and take their second freshman mathematics course at a higher level, for example, MATH 1260 (Complex Analysis), MATH 1610 (Probability), or MATH 1620 (Mathematical Statistics). Alternatively, for some engineering concentrations, this second MATH credit requirement may be satisfied by taking a course from the Applied Mathematics Department, such as APMA 0350 (Applied Ordinary Differential Equations), APMA 0360 (Applied Partial Differential Equations), APMA 1650 (Statistical Inference) or APMA 1210 (Operations Research: Deterministic Models) if one of those courses listed is not taken for two APMA concentration credits. Details regarding the mathematics requirement for each concentration are listed in the corresponding programs.

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 two 1000-level courses, one must be a design course (ideally capstone or any design course in accredited Sc.B. programs) or be an independent study course that incorporates elements of student project design (must meet Brown course hour requirements), and the other course would be any 1000-level advanced (with pre-requisites) engineering in-classroom experience course. 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, in the table below, <u>cannot be used</u> to satisfy the Engineering course requirement for the A.B. Therefore, the program of study must be developed through consultation with the Concentration Advisor.

ENGN 0020	Transforming Society-Technology and Choices for the Future
ENGN 0090	Management of Industrial and Nonprofit Organizations
ENGN 0130	The Engineer's Burden: Why Changing the World is Difficult
ENGN 0260	Mechanical Technology
ENGN 0350	Art Fluid Engineering
ENGN 0610	Systems Thinking
ENGN 0620	Design Brief
ENGN 0900	Managerial Decision Making
ENGN 0930A	Appropriate Technology
ENGN 0930C	DesignStudio
ENGN 1010	The Entrepreneurial Process
ENGN 1800	Social Impact of Emerging Technologies: The Role of Scientists and Engineers
ENGN 1931Q	Entrepreneurial Management in Adversity
ENGN 1931W	Selling & Sales Leadership in the Entrepreneurial Environment
ENGN 1932M	Foundations of Internet Communication Systems
ENGN 2110	Business Engineering Fundamentals I
ENGN 2120	Business Engineering Fundamentals II
ENGN 2130	Innovation and Technology Management
ENGN 2140	Innovation and Technology Management II
ENGN 2150	Technology Entrepreneurship and Commercialization I
ENGN 2180	Globalization Immersion Experience and Entrepreneurship Laboratory
ENGN 2160	Technology Entrepreneurship and Commercialization II

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), biology, 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.

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 for or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

Biomedical Engineering Concentration Requirements

Biomedical Engineering (https://engineering.brown.edu/undergraduate/ (https://engineering.brown.edu/undergraduate/concentrations/biomedical-engineering/)concentrations/biomedical-engineering/ (https://engineering.brown.edu/undergraduate/concentrations/biomedical-engineering/)) is a dynamic and growing field based upon the application of the tools of engineering to the subject matter of biology and medicine. The undergraduate program in biomedical engineering is an interdisciplinary concentration structured as a joint program between the Division of Biology and Medicine and the School of Engineering. Students can take courses from and do research with faculty from engineering, the various departments of biology, and the Brown-affiliated hospitals in Rhode Island. The Biomedical Engineering (BME) concentration shares much of the core with the other engineering programs, but the program's primary emphasis is on the fundamentals of biomedical engineering, while also allowing students to personalize their curriculum. Biomedical engineers design new drugs, genetically engineer organisms, and devise new medical devices and instruments. They also use their understanding of biology to advance synthetic and naturally-derived materials and products. BME students learn to apply the principles of engineering and science, along with problem solving skills and critical thinking to a broad spectrum of engineering problems. Further, BME is a sound foundation for lifelong education with its emphasis on the use of teamwork, effective communication skills, and an understanding of broad social, ethical, economic and environmental consequences. The biomedical engineering curriculum at Brown prepares students for careers in biomedical engineering and biotechnology, as well as careers in diverse areas such as medicine, law, business, and health care delivery.

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 life sciences and medicine. 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 and is structured to include more science courses and electives that introduce cutting edge areas in the field of BME.

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 (https://bulletin.brown.edu/engineering/) for explicit guidelines.

Standard program for the Sc.B. degree

1. Core Courses		
ENGN 0030	Introduction to Engineering	1
or ENGN 0032	Introduction to Engineering: Design	
ENGN 0040	Engineering Statics and Dynamics	1
ENGN 0510	Electricity and Magnetism	1
or ENGN 0520	Electrical Circuits and Signals	
ENGN 0720	Thermodynamics	1
ENGN 0810	Fluid Mechanics	1
CHEM 0330	Equilibrium, Rate, and Structure	1
MATH 0190	Single Variable Calculus, Part II (Physics/Engineering)	1
or MATH 0100	Single Variable Calculus, Part II	
CHEM 0350	Organic Chemistry I	1
MATH 0200	Multivariable Calculus (Physics/Engineering)	1
or MATH 0180	Multivariable Calculus	
or MATH 0350	Multivariable Calculus With Theory	
APMA 0350	Applied Ordinary Differential Equations [1]	1
APMA 1650	Introduction to Probability and Statistics with Calculus	1
or BIOL 0495	Statistical Analysis of Biological Data	
or PHP 1510	Principles of Biostatistics and Data Analysis	
or APMA 1655	Introduction to Probability and Statistics with Theory	
2. Upper Level Biomedical Engineering Curriculum		
ENGN 1110	Transport and Biotransport Processes	1
ENGN 1210	Biomechanics	1
ENGN 1230	Instrumentation Design	1
ENGN 1490	Biomaterials	1
BIOL 0800	Principles of Physiology	1
3. Additional Biomedical Engineering Electives: Complete at least 3 courses from the following groups; other upper-level courses are subject to Concentration Advisor approval.		**3**
Select one or two of the following:		
CSCI 1810	Computational Molecular Biology	
or 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 1945	Immunoengineering	
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	
BIOL 1150	Stem Cell Engineering	
BIOL 2110	Drug and Gene Delivery	
At least one or two more courses from:		
BIOL 0280	Biochemistry	
BIOL 0470	Genetics	
BIOL 0500	Cell and Molecular Biology	
BIOL 0510	Introductory Microbiology	
BIOL 0530	Principles of Immunology	
BIOL 1090	Polymer Science for Biomaterials	
BIOL 1100	Cell Physiology and Biophysics	

BIOL 1555	Methods in Informatics and Data Science for Health	
APMA 1070	Quantitative Models of Biological Systems	
CHEM 0360	Organic Chemistry II	
ENGN 2910G	Topics in Translational Research and Technologies	
NEUR 1020	Principles of Neurobiology	
NEUR 1440	Mechanisms and Meaning of Neural Dynamics	
PHYS 1610	Biological Physics	
BIOL 1810	21st Century Applications in Cell and Molecular Biology	
4. Capstone Design [2]		
ENGN 1240	Biomedical Engineering Design and Innovation	1
ENGN 1250	Biomedical Engineering Design and Innovation II	1
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 academic year 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.

Professional Track

The requirements for all undergraduate professional tracks within concentrations are standardized and additional information can be found here:

https://nextbulletin.brown.edu/undergradproftrack/ (http://bulletin.brown.edu/undergradproftrack/)

Chemical Engineering Concentration Requirements

The Sc.B. program in Chemical Engineering prepares students for any field in the chemical sciences. The program emphasizes a molecular engineering approach to problem-solving. Students will learn how engineering at the atomic scale can be used to solve some of the most pressing technical challenges facing society. The program provides a rigorous foundation in engineering fundamentals and space for students to craft a program for their desired goals. Our students go on to work in industry, start-ups, consulting, graduate and professional schools, and many other fields.

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/

Please note that all students concentrating in Engineering need to file a concentration declaration using the University's ASK advising system. This declaration must be first reviewed by the relevant Concentration Advisor and then approved by the Director of Undergraduate Studies after assuring compliance with all relevant program and accreditation requirements.

Standard Program for the Sc.B. degree

Mathematics Requirements

As mathematics is a cornerstone of all engineering programs, significant attention is given to early preparation in mathematics in engineering concentrations. It is recognized that students entering Brown will have different levels of mathematics preparation, and the following is offered as general guidance, though the actual choices of courses should be made in consultation with an exploratory advisor. MATH 0190 (or MATH 0100), followed by MATH 0200 (or MATH 0180) is the preferred sequence of courses to be taken in the freshman year. MATH 0100 and MATH 0180 offer content like that in MATH 0190 and MATH 0200, respectively, but the latter courses are highly recommended for future engineering students because they offer more examples of relevance to the field. Students who would prefer, or require, a more introductory level calculus course may start the sequence with MATH 0090. They may then take MATH 0200 (or MATH 0180) in the subsequent semester and in that case, would receive engineering concentration credit equivalent to that which they would have received having taken MATH 0190 and MATH 0200. However, students who find that the step up from MATH 0090 to MATH 0200 is too challenging, have a choice to take MATH 0190 (or MATH 0100) upon completion of MATH 0090, but in this case, MATH 0090 would not carry engineering concentration credit and the student would then need to take MATH 0200 (or MATH 0180) in the sophomore year.

Students who have taken Advanced Placement (AP) calculus courses in high school and/or have shown proficiency through AP examinations may start the calculus sequence at a higher level than that suggested above. If a student has AP credit and accepts to use it, it then allows the student to place out of MATH 0190 (or MATH 0100). These students should enroll in the appropriate higher-level math course, e.g., MATH 0200 (or MATH 0180) or possibly MATH 0350 (a more theoretical course that covers similar material). Although it is impossible to place out of MATH 0200 or MATH 0350 with AP credit, we recognize that some students enter with an even higher level of preparation. Those students are advised to enroll in MATH 0520 (Linear Algebra), or MATH 0540 (Honors Linear Algebra), and take their second freshman mathematics course at a higher level, for example, MATH 1460 (Complex Analysis), MATH 1210 (Probability), or MATH 1220 (Mathematical Statistics). Alternatively, for some engineering concentrations, this second MATH credit requirement may be satisfied by taking a course from the Applied Mathematics Department, such as APMA 0350 (Applied Ordinary Differential Equations), APMA 0360 (Applied Partial Differential Equations), APMA 1650 (Statistical Inference) or APMA 1210 (Operations Research: Deterministic Models) if one of those courses listed is not taken for two APMA concentration credits. Details regarding the mathematics requirement for each concentration are listed in the corresponding programs.

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.

1. Core Courses:		
ENGN 0030	Introduction to Engineering	1
or ENGN 0032	Introduction to Engineering: Design	
ENGN 0040	Engineering Statics and Dynamics	1
ENGN 0410	Materials Science	1
ENGN 0510	Electricity and Magnetism	1
ENGN 0520	Electrical Circuits and Signals	1
or ENGN 0500	Digital Computing Systems	
ENGN 0720	Thermodynamics	1
ENGN 0810	Fluid Mechanics	1
CHEM 0330	Equilibrium, Rate, and Structure	1
BIOL 0200	The Foundation of Living Systems	1
MATH 0190	Single Variable Calculus, Part II (Physics/Engineering)	1
or MATH 0100	Single Variable Calculus, Part II	
MATH 0200	Multivariable Calculus (Physics/Engineering)	1
or MATH 0180	Multivariable Calculus	
or MATH 0350	Multivariable Calculus With Theory	
APMA 0350	Applied Ordinary Differential Equations	1
APMA 0360	Applied Partial Differential Equations I	1
or APMA 1650	Introduction to Probability and Statistics with Calculus	
or APMA 1655	Introduction to Probability and Statistics with Theory	
or CSCI 1450	Advanced Introduction to Probability for Computing and Data Science	
2. Upper-Level Chemical Engineering Curriculum		
ENGN 1110	Transport and Biotransport Processes	1
ENGN 1120	Reaction Kinetics and Reactor Design [1]	1
ENGN 1130	Chemical Engineering Thermodynamics [1]	1
ENGN 1710	Heat and Mass Transfer	1
CHEM 0350	Organic Chemistry I	1
Advanced Chemistry elective course [2]		
CHEM 0360	Organic Chemistry II	1
or CHEM 0400	Biophysical and Bioinorganic Chemistry	
or CHEM 0500	Inorganic Chemistry	
or CHEM 1140	Physical Chemistry: Quantum Chemistry	
Advanced Engineering or Natural Sciences elective course [3]		1
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. ENGN 1120 and ENGN 1130 are only offered in alternate years.
2. An advanced chemistry course approved by Concentration Advisor; the courses listed have been pre-approved for this requirement.
3. An advanced course in the natural sciences approved by the Concentration Advisor. For suggestions of acceptable courses that fulfill this requirement, please see the Concentration Advisor.

Special Sc.B. Concentrations (non-accredited)

In addition to the standard program 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 Track

The requirements for all undergraduate professional tracks within concentrations are standardized and additional information can be found here:

https://nextbulletin.brown.edu/undergradproftrack/ (http://bulletin.brown.edu/undergradproftrack/)

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 for or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

Computer Engineering Concentration Requirements

Computer engineers design computer hardware (from chips to servers), communication and network systems, and the smart digital devices that continue to revolutionize how we live and work. They also write the software to run these systems, constantly innovating to improve performance to meet our growing technological needs. They are at the forefront of cybersecurity, machine intelligence, networking, embedded systems, and robotics. They are proficient in both electrical engineering and computer science and are employed in every industry or field that requires computer hardware.

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.

Please note that all students concentrating in Engineering need to file a concentration declaration using the University's ASK advising system. This declaration must be first reviewed by the relevant Concentration Advisor and then approved by the Director of Undergraduate Studies after assuring compliance with all relevant program and accreditation requirements.

Standard Program for the Sc.B. degree

Mathematics Requirements

As mathematics is a cornerstone of all engineering programs, significant attention is given to early preparation in mathematics in engineering concentrations. It is recognized that students entering Brown will have different levels of mathematics preparation, and the following is offered as general guidance, though the actual choices of courses should be made in consultation with an exploratory advisor. MATH 0190 (or MATH 0100), followed by MATH 0200 (or MATH 0180) is the preferred sequence of courses to be taken in the freshman year. MATH 0100 and MATH 0180 offer content like that in MATH 0190 and MATH 0100, respectively, but the latter courses are highly recommended for future engineering students because they offer more examples of relevance to the field. Students who would prefer, or require, a more introductory level calculus course may start the sequence with MATH 0090. They may then take MATH 0200 (or MATH 0180) in the subsequent semester and in that case, would receive engineering concentration credit equivalent to that which they would have received having taken MATH 0190 and MATH 0200. However, students who find that the step up from MATH 0090 to MATH 0200 is too challenging, have a choice to take MATH 0190 (or MATH 0100) upon completion of MATH 0090, but in this case, MATH 0090 would not carry engineering concentration credit and the student would then need to take MATH 0200 (or MATH 0180) in the sophomore year.

Students who have taken Advanced Placement (AP) calculus courses in high school and/or have shown proficiency through AP examinations may start the calculus sequence at a higher level than that suggested above. If a student has AP credit and accepts to use it, it then allows the student to place out of MATH 0190 (or MATH 0100). These students should enroll in the appropriate higher-level math course, e.g., MATH 0200 (or MATH 0180) or possibly MATH 0350 (a more theoretical course that covers similar material). Although it is impossible to place out of MATH 0200 or MATH 0350 with AP credit, we recognize that some students enter with an even higher level of preparation. Those students are advised to enroll in MATH 0520 (Linear Algebra), or MATH 0540 (Honors Linear Algebra), and take their second freshman mathematics course at a higher level, for example, MATH 1460 (Complex Analysis), MATH 1210 (Probability), or MATH 1220 (Mathematical Statistics). Alternatively, for some engineering concentrations, this second MATH credit requirement may be satisfied by taking a course from the Applied Mathematics Department, such as APMA 0350 (Applied Ordinary Differential Equations), APMA 0360 (Applied Partial Differential Equations), APMA 1650 (Statistical Inference) or APMA 1210 (Operations Research: Deterministic Models) if one of those courses listed is not taken for two APMA concentration credits. Details regarding the mathematics requirement for each concentration are listed in the corresponding programs.

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.

1. Core Courses:		
ENGN 0030	Introduction to Engineering	1
or ENGN 0032	Introduction to Engineering: Design	
ENGN 0040	Engineering Statics and Dynamics	1
ENGN 0510	Electricity and Magnetism	1
ENGN 0520	Electrical Circuits and Signals	1
APMA 1650	Introduction to Probability and Statistics with Calculus	1
or APMA 1655	Introduction to Probability and Statistics with Theory	
or CSCI 1450	Advanced Introduction to Probability for Computing and Data Science	
MATH 0190	Single Variable Calculus, Part II (Physics/Engineering)	1
or MATH 0100	Single Variable Calculus, Part II	
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]	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):		2
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)	
OR		
CSCI 0111	Computing Foundations: Data [2]	
and		
CSCI 0112	Computing Foundations: Program Organization	
and		
CSCI 0200	Program Design with Data Structures and Algorithms	
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: [3]		1
CSCI 0330	Introduction to Computer Systems	
or CSCI 0300	Fundamentals of Computer Systems	
ENGN 0500	Digital Computing Systems	
CSCI 0320	Introduction to Software Engineering	
CSCI 1230	Introduction to Computer Graphics	
CSCI 1380	Distributed Computer Systems	
CSCI 1670	Operating Systems	
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. [4]		3
ENGN 1220	Neuroengineering	
ENGN 1450	Properties and Processing of Electronic Materials	
ENGN 1560	Applications in Microwave Communications	
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 1650	Embedded Microprocessor Design [5]	
ENGN 1690	Photonics Devices and Sensors	
ENGN 1930B	Biomedical Optics	
ENGN 1931A	Photovoltaics Engineering	
ENGN 1931F	Introduction to Power Engineering	
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 2560	Computer Vision	
ENGN 2620	Solid State Quantum and Optoelectronics	
ENGN 2911X	Reconfigurable Computing	
ENGN 2912B	Scientific Programming in C++	
ENGN 2912K	Mixed-Signal Electronic Design	
ENGN 2912U	Coordinated Mobile Robotics	
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 1300	Interaction Design	
CSCI 1380	Distributed Computer Systems	
CSCI 1411	Foundations of AI	
CSCI 1430	Computer Vision	
CSCI 1470	Deep Learning	
CSCI 1570	Design and Analysis of Algorithms	
CSCI 1600	Real-Time and Embedded Software	
CSCI 1660	Introduction to Computer Systems Security	
CSCI 1670	Operating Systems	
CSCI 1680	Computer Networks	
CSCI 1730	Design and Implementation of Programming Languages	
CSCI 1951R	Introduction to Robotics	
3. Capstone Design [6]		**1**
ENGN 1650	Embedded Microprocessor Design [5]	
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 a Biology course beyond BIOL 0200, subject to Concentration Advisor approval
2. Subject to approval by the Concentration Advisor, the third upper-level elective may optionally be chosen from another department, such as CLPS, NEUR, PHYS or CHEM, if it has a significant quantitative physical science emphasis.
3. CSCI 1952Y cannot be used as a CS elective due to its overlap with ENGN 1640, which is a required course.
4. Students wishing to go directly from CSCI 0111 (https://bulletin.brown.edu/search/?P=CSCI%200111) to CSCI 0200 (https://bulletin.brown.edu/search/?P=CSCI%200200) (without CSCI 0112 (https://bulletin.brown.edu/search/?P=CSCI%200112)) will need to successfully complete additional exercises to receive an instructor override code for CSCI 0200 (https://bulletin.brown.edu/search/?P=CSCI%200200).
5. ENGN 1650 cannot be counted as an elective and capstone simultaneously. It can only be either elective or capstone.
6. 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/)

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 Track

The requirements for all undergraduate professional tracks within concentrations are standardized and additional information can be found here:

https://nextbulletin.brown.edu/undergradproftrack/ (http://bulletin.brown.edu/undergradproftrack/)

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 for or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

Design Engineering Concentration Requirements

Design Engineering (https://engineering.brown.edu/undergraduate/concentrations/design-engineering/) (DE) teaches students to understand not just the how and what, but the why and why not behind the creation of technologically enabled products, services and systems. Methodologies, frameworks and analytical tools to evaluate strategic and systemic implications and consequences of these products, services and systems are considered. DE prepares students to (a) effectively apply engineering principles and quantitative analysis to make design decisions, (b) utilize complementary and conflicting principles from domains other than engineering in design decisions, (c) adeptly apply systemic principles to show interactions within and between systems, and (d) achieve fluency in human-centered and systems design processes and principles to analyze and synthesize responses to complex real-world problems.

Visit https://engineering.brown.edu/undergraduate/concentrations/design-engineering

The DE program has 19 required courses and a required narrative explaining why the student is choosing Design Engineering, their proposed pathway, and how their courses support that pathway. Course requirements include three courses in mathematics; one introductory engineering design course; one engineering gateway course; one natural science course; one computer science course; two engineering design courses (ENGN 0610 and ENGN 0620); three cognitive, psychological or social science courses (either from the list provided or with concentration advisor approval); and six upper-level courses curated by a student's chosen pathway focus, from which four must be engineering courses. The program culminates with a capstone, design or independent study experience. Brown's Design Engineering Bachelor of Science degree is non-ABET accredited.

Program Requirements

Introduction to Engineering		
ENGN 0032	Introduction to Engineering: Design	1
or ENGN 0030	Introduction to Engineering	
Engineering Gateway (courses selected should include those required for the student's proposed pathway)		
ENGN 0040	Engineering Statics and Dynamics	1
or ENGN 0410	Materials Science	
or ENGN 0490	Fundamentals of Environmental Engineering	
or ENGN 0500	Digital Computing Systems	
or ENGN 1490	Biomaterials	
Basic Physical/Life Science		**1**
BIOL 0200	The Foundation of Living Systems	
CHEM 0330	Equilibrium, Rate, and Structure	
NEUR 0010	The Brain: An Introduction to Neuroscience	
Computer Science		**1**
CSCI 0111	Computing Foundations: Data	
CSCI 0150	Introduction to Object-Oriented Programming and Computer Science	
CSCI 0170	Computer Science: An Integrated Introduction	
CSCI 0190	Accelerated Introduction to Computer Science	
APMA 0160	Introduction to Scientific Computing	
Mathematics: Calculus and Methods of Applied Mathematics and Statistics		
MATH 0200	Multivariable Calculus (Physics/Engineering)	1
or MATH 0180	Multivariable Calculus	
APMA 0350	Applied Ordinary Differential Equations	1
A third mathematics course from the following list:		1
MATH 0100	Single Variable Calculus, Part II	
MATH 0190	Single Variable Calculus, Part II (Physics/Engineering)	
APMA 0360	Applied Partial Differential Equations I	
APMA 1650	Introduction to Probability and Statistics with Calculus	
APMA 1655	Introduction to Probability and Statistics with Theory	
CSCI 1450	Advanced Introduction to Probability for Computing and Data Science	
MATH 0520	Linear Algebra	
MATH 0540	Linear Algebra With Theory	
Design Engineering Specific Requirements		
ENGN 0610	Systems Thinking	1
ENGN 0620	Design Brief	1
Social Science Research, Decision Making and Societal Context		
One course that covers Social Science Research Methods:		1
ANTH 1940	Ethnographic Research Methods	
SOC 1117	Focus Groups for Market and Social Research	
SOC 1118	Context Research for Innovation	
POLS 0500	Foundations of Political Analysis	
Or an equivalent course approved by the Concentration Advisor		
One course on Decision Making and Design:		1
CPSY 0220	Making Decisions	
CPSY 0010	Mind, Brain and Behavior: An Interdisciplinary Approach	
CPSY 0700	Social Psychology	
CPSY 1730	Psychology in Business and Economics	
EDUC 0800	Introduction to Human Development and Education	
PHIL 1610	Decision Theory: Foundations and Applications	
Or an equivalent course approved by the Concentration Advisor		
One course on Societal Context for Design:		1
AMST 1611S	US Popular Culture	
ANTH 0100	Introduction to Cultural Anthropology	
ANTH 1236	Urban Life: Anthropology in and of the City	
ARCH 0755	Engineering and Technology in the Ancient World	
ECON 0110	Principles of Economics	
ECON 1390	Inequality of Income, Wealth, and Health in the United States	
HIAA 0140	Structural and Architectural Analysis	
HIAA 1171	Cities, Landscapes, and Design in the Age of Pandemics	
PHIL 0401	Ethics of Digital Technology	
PHIL 0403	Ethics and Politics of Data	
PHIL 1430	Moral Theories	
TAPS 0220	Persuasive Communication	
URBN 1870D	Downtown Development	
Or an equivalent course approved by the Concentration Advisor		

Advanced Courses: Six engineering and/or engineering-related courses, at least four of which are ENGN courses, including two ENGN courses that are above the 1000-level (cannot be Entrepreneurship or Innovation Management and Entrepreneurship (PRIME) program courses). The fifth and the sixth courses can be non-introductory STEM courses. The pathway must be approved by the Concentration Advisor and constitute a coherent body of work. [1]		**6**
One Capstone, Design or Independent Study		**1**
ENGN 1000	Projects in Engineering Design I	
ENGN 1001	Projects in Engineering Design II	
ENGN 1140	Chemical Process Design	
ENGN 1150	Environmental Engineering Design	
ENGN 1230	Instrumentation Design	
ENGN 1620	Analysis and Design of Electronic Circuits	
ENGN 1640	Design of Computing Systems	
ENGN 1650	Embedded Microprocessor Design	
ENGN 1740	Computer Aided Visualization and Design	
ENGN 1760	Design of Space Systems	
ENGN 1930L	Biomedical Engineering Design and Innovation	
ENGN 1930M	Industrial Design	
ENGN 1931D	Design of Mechanical Assemblies	
ENGN 1931L	Biomedical Engineering Design and Innovation II	
ENGN 1972	Independent Study in Engineering Design	
ENGN 1973	Independent Study in Engineering Design	
Total Credits		**19**

[1] The following courses do not qualify for this purpose: ENGN 0020, ENGN 0090, ENGN 0130, ENGN 0350, ENGN 0900, ENGN 0930A, ENGN 1010, ENGN 1800, ENGN 1931H, ENGN 1931J, ENGN 1931Q, ENGN 1931W, ENGN 1932D, ENGN 2000, ENGN 2040, ENGN 2060, ENGN 2095, ENGN 2110, ENGN 2120, ENGN 2125, ENGN 2130, ENGN 2140, ENGN 2150, ENGN 2160, ENGN 2172, ENGN 2173, ENGN 2180

Electrical Engineering Concentration Requirements

The Sc.B. program in Electrical Engineering equips students with a solid foundation for careers in electrical engineering and related fields, to advance the knowledge base for future technologies, and to merge teaching, scholarship, and practice in the pursuit of solutions to human needs. Electrical engineers design and manufacture microelectronic hardware; sensors; biomedical instrumentation; communication systems; control systems; radar and navigation equipment, as well as power generation and distribution equipment and propulsion systems. The professional organization for electrical engineers, the Institute of Electrical and Electronics Engineers (IEEE), has over 400,000 members worldwide.

The curriculum consists of an interdisciplinary engineering core that includes courses in engineering, mathematics, and computer science, followed by advanced courses in electrical engineering, which include linear systems, analog and digital electronics, advanced science (typically modern physics or quantum mechanics) and three upper-level EE courses selected by the students. The program culminates with the capstone project course.

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/

Please note that all students concentrating in Engineering need to file a concentration declaration using the University's ASK advising system. This declaration must be first reviewed by the relevant Concentration Advisor and then approved by the Director of Undergraduate Studies after assuring compliance with all relevant program and accreditation requirements.

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.

Standard Program for the Sc.B. degree

Mathematics Requirements

As mathematics is a cornerstone of all engineering programs, significant attention is given to early preparation in mathematics in engineering concentrations. It is recognized that students entering Brown will have different levels of mathematics preparation, and the following is offered as general guidance, though the actual choices of courses should be made in consultation with an exploratory advisor. MATH 0190 (or MATH 0100), followed by MATH 0200 (or MATH 0180) is the preferred sequence of courses to be taken in the freshman year. MATH 0100 and MATH 0180 offer content like that in MATH 0190 and MATH 0200, respectively, but the latter courses are highly recommended for future engineering students because they offer more examples of relevance to the field. Students who would prefer, or require, a more introductory level calculus course may start the sequence with MATH 0090. They may then take MATH 0200 (or MATH 0180) in the subsequent semester and in that case, would receive engineering concentration credit equivalent to that which they would have received having taken MATH 0190 and MATH 0200. However, students who find that the step up from MATH 0090 to MATH 0200 is too challenging, have a choice to take MATH 0190 (or MATH 0100) upon completion of MATH 0090, but in this case, MATH 0090 would not carry engineering concentration credit and the student would then need to take MATH 0200 (or MATH 0180) in the sophomore year.

Students who have taken Advanced Placement (AP) calculus courses in high school and/or have shown proficiency through AP examinations may start the calculus sequence at a higher level than that suggested above. If a student has AP credit and accepts to use it, it then allows the student to place out of MATH 0190 (or MATH 0100).

These students should enroll in the appropriate higher-level math course, e.g., MATH 0200 (or MATH 0180) or possibly MATH 0350 (a more theoretical course that covers similar material). Although it is impossible to place out of MATH 0200 or MATH 0350 with AP credit, we recognize that some students enter with an even higher level of preparation. Those students are advised to enroll in MATH 0520 (Linear Algebra), or MATH 0540 (Honors Linear Algebra), and take their second freshman mathematics course at a higher level, for example, MATH 1460 (Complex Analysis), MATH 1210 (Probability), or MATH 1220 (Mathematical Statistics). Alternatively, for some engineering concentrations, this second MATH credit requirement may be satisfied by taking a course from the Applied Mathematics Department, such as APMA 0350 (Applied Ordinary Differential Equations), APMA 0360 (Applied Partial Differential Equations), APMA 1650 (Statistical Inference) or APMA 1210 (Operations Research: Deterministic Models) if one of those courses listed is not taken for two APMA concentration credits.

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.

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.

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.

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.

1. Core Courses:		
ENGN 0030	Introduction to Engineering	1
or ENGN 0032	Introduction to Engineering: Design	
ENGN 0040	Engineering Statics and Dynamics	1
ENGN 0410	Materials Science	1
ENGN 0510	Electricity and Magnetism	1
ENGN 0520	Electrical Circuits and Signals	1
ENGN 0720	Thermodynamics	1
ENGN 0310	Mechanics of Solids and Structures	1
or ENGN 0500	Digital Computing Systems	
or ENGN 0810	Fluid Mechanics	
or CSCI 0200	Program Design with Data Structures and Algorithms	
CHEM 0330	Equilibrium, Rate, and Structure	1
or MATH 0520	Linear Algebra	
or MATH 0540	Linear Algebra With Theory	
or APMA 0360	Applied Partial Differential Equations I	
MATH 0190	Single Variable Calculus, Part II (Physics/Engineering)	1
or MATH 0100	Single Variable Calculus, Part II	
MATH 0200	Multivariable Calculus (Physics/Engineering)	1
or MATH 0180	Multivariable Calculus	
or MATH 0350	Multivariable Calculus With Theory	
APMA 0350	Applied Ordinary Differential Equations	1
APMA 1650	Introduction to Probability and Statistics with Calculus [1]	1
or APMA 1710	Information Theory	
or CSCI 1450	Advanced Introduction to Probability for Computing and Data Science	
CSCI 0150	Introduction to Object-Oriented Programming and Computer Science [2]	1
or CSCI 0111	Computing Foundations: Data	
or CSCI 0170	Computer Science: An Integrated Introduction	
or CSCI 0190	Accelerated Introduction to Computer Science	
or APMA 0160	Introduction to Scientific Computing	
or ENGN 1931Z	Interfaces, Information and Automation	
2. Upper-Level Electrical Engineering Curriculum		
ENGN 1570	Linear System Analysis	1
ENGN 1620	Analysis and Design of Electronic Circuits	1
ENGN 1630	Digital Electronics Systems Design	1
PHYS 0790	Physics of Matter [3]	1
or PHYS 1410	Quantum Mechanics A	

3. Electrical Engineering Specialization - Complete at least three courses from the following groups:		**3**
At least one advanced Electrical Engineering foundations course:		
ENGN 1230	Instrumentation Design	
ENGN 1580	Communication Systems	
ENGN 1590	Semiconductor Devices	
ENGN 1600	Design and Implementation of Digital Integrated Circuits	
ENGN 1610	Image Understanding	
ENGN 1640	Design of Computing Systems	
Up to two other Electrical Engineering courses [4]		
ENGN 1220	Neuroengineering	
ENGN 1560	Applications in Microwave Communications	
ENGN 1650	Embedded Microprocessor Design [5]	
ENGN 1680	Design and Fabrication of Semiconductor Devices	
ENGN 1690	Photonics Devices and Sensors	
ENGN 1730	Lasers and Nonlinear Optics	
ENGN 1790	Quantum Optics	
ENGN 1930B	Biomedical Optics	
ENGN 1931A	Photovoltaics Engineering	
ENGN 1931F	Introduction to Power Engineering	
ENGN 1931I	Design of Robotic Systems	
ENGN 1931Y	Control Systems Engineering	
ENGN 1931Z	Interfaces, Information and Automation	
Up to one interdisciplinary engineering science course: [6]		
CPSY 1492	Computational Cognitive Neuroscience	
ENGN 1370	Advanced Engineering Mechanics	
ENGN 1450	Properties and Processing of Electronic Materials	
NEUR 2110	Statistical Neuroscience	
PHYS 1420	Quantum Mechanics B	
4. Capstone Design: At least one course from the following: [7]		**1**
ENGN 1650	Embedded Microprocessor Design [5]	
or ENGN 1000	Projects in Engineering Design I	
or ENGN 1001	Projects in Engineering Design II	
5. General Education Requirement: At least four approved courses must be taken in humanities and social sciences		
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 1000-level PHYS courses may be taken subject to Concentration Advisor's approval.
4. 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.
5. ENGN 1650 cannot be counted as an elective and capstone simultaneously. It can only be either elective or capstone.
6. Or CSCI course beyond CSCI 0200, subject to Concentration Advisor approval.
7. 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/)

Professional Track

The requirements for all undergraduate professional tracks within concentrations are standardized and additional information can be found here:

https://bulletin.brown.edu/undergradproftrack/

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 for or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

Environmental Engineering Concentration Requirements

The Sc.B. program in Environmental Engineering provides students with the tools to develop sustainable solutions to complicated environmental problems and design real-world solutions that consider risk, sustainability, life-cycle principles, and environmental impacts. Environmental engineers use the principles of engineering, mathematics, biology, and chemistry to develop and implement engineering solutions to protect human health and the environment from the adverse impacts of environmental pollution. Their work includes water and wastewater treatment, air pollution control, soil and groundwater remediation, site characterization and risk assessment, life cycle assessment, and climate change mitigation.

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/

Please note that all students concentrating in Engineering need to file a concentration declaration using the University's ASK advising system. This declaration must be first reviewed by the relevant Concentration Advisor and then approved by the Director of Undergraduate Studies after assuring compliance with all relevant program and accreditation requirements.

Standard Program for the Sc.B. degree

Mathematics Requirements

As mathematics is a cornerstone of all engineering programs, significant attention is given to early preparation in mathematics in engineering concentrations. It is recognized that students entering Brown will have different levels of mathematics preparation, and the following is offered as general guidance, though the actual choices of courses should be made in consultation with an exploratory advisor. MATH 0190 (or MATH 0100), followed by MATH 0200 (or MATH 0180) is the preferred sequence of courses to be taken in the freshman year. MATH 0100 and MATH 0180 offer content like that in MATH 0190 and MATH 0200, respectively, but the latter courses are highly recommended for future engineering students because they offer more examples of relevance to the field. Students who would prefer, or require, a more introductory level calculus course may start the sequence with MATH 0090. They may then take MATH 0200 (or MATH 0180) in the subsequent semester and in that case, would receive engineering concentration credit equivalent to that which they would have received having taken MATH 0190 and MATH 0200. However, students who find that the step up from MATH 0090 to MATH 0200 is too challenging, have a choice to take MATH 0190 (or MATH 0100) upon completion of MATH 0090, but in this case, MATH 0090 would not carry engineering concentration credit and the student would then need to take MATH 0200 (or MATH 0180) in the sophomore year.

Students who have taken Advanced Placement (AP) calculus courses in high school and/or have shown proficiency through AP examinations may start the calculus sequence at a higher level than that suggested above. If a student has AP credit and accepts to use it, it then allows the student to place out of MATH 0190 (or MATH 0100). These students should enroll in the appropriate higher-level math course, e.g., MATH 0200 (or MATH 0180) or possibly MATH 0350 (a more theoretical course that covers similar material). Although it is impossible to place out of MATH 0200 or MATH 0350 with AP credit, we recognize that some students enter with an even higher level of preparation. Those students are advised to enroll in MATH 0520 (Linear Algebra), or MATH 0540 (Honors Linear Algebra), and take their second freshman mathematics course at a higher level, for example, MATH 1460 (Complex Analysis), MATH 1210 (Probability), or MATH 1220 (Mathematical Statistics). Alternatively, for some engineering concentrations, this second MATH credit requirement may be satisfied by taking a course from the Applied Mathematics Department, such as APMA 0350 (Applied Ordinary Differential Equations), APMA 0360 (Applied Partial Differential Equations), APMA 1650 (Statistical Inference) or APMA 1210 (Operations Research: Deterministic Models) if one of those courses listed is not taken for two APMA concentration credits. Details regarding the mathematics requirement for each concentration are listed in the corresponding programs.

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.

1. Core Courses:		
ENGN 0030	Introduction to Engineering	1
or ENGN 0032	Introduction to Engineering: Design	
ENGN 0040	Engineering Statics and Dynamics	1
ENGN 0410	Materials Science	1
or ENGN 1490	Biomaterials	
ENGN 0490	Fundamentals of Environmental Engineering	1
CSCI 0111	Computing Foundations: Data	1
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 0500	Digital Computing Systems	
or ENGN 0510	Electricity and Magnetism	
or ENGN 0520	Electrical Circuits and Signals	
ENGN 0720	Thermodynamics	1
ENGN 0810	Fluid Mechanics	1
BIOL 0200	The Foundation of Living Systems	1
CHEM 0330	Equilibrium, Rate, and Structure	1
MATH 0190	Single Variable Calculus, Part II (Physics/Engineering)	1
or MATH 0100	Single Variable Calculus, Part II	
MATH 0200	Multivariable Calculus (Physics/Engineering)	1
or MATH 0180	Multivariable Calculus	
or MATH 0350	Multivariable Calculus With Theory	
APMA 0350	Applied Ordinary Differential Equations [1]	1

or APMA 0360	Applied Partial Differential Equations I	
APMA 1650	Introduction to Probability and Statistics with Calculus	1
or APMA 1655	Introduction to Probability and Statistics with Theory	
2. Advanced Science Courses		
EEPS 1370	Environmental Geochemistry	1
or EEPS 0850	Weather and Climate	
or EEPS 1310	Global Water Cycle	
or EEPS 1320	Introduction to Geographic Information Systems for Environmental Applications	
or EEPS 1330	Global Environmental Remote Sensing	
or EEPS 1430	Principles of Planetary Climate	
or EEPS 1520	Ocean Circulation and Climate	
or EEPS 1710	Remote Sensing of Earth and Planetary Surfaces	
BIOL 0420	Principles of Ecology	1
or BIOL 0480	Evolutionary Biology	
or BIOL 0500	Cell and Molecular Biology	
or BIOL 0800	Principles of Physiology	
or BIOL 1470	Conservation Biology	
3. Upper-Level Environmental Engineering Curriculum [2]		
ENGN 1340	Water Supply and Treatment Systems - Technology and Sustainability	1
Plus four advanced engineering courses from the list below		4
ENGN 1110	Transport and Biotransport Processes	
ENGN 1120	Reaction Kinetics and Reactor Design	
ENGN 1130	Chemical Engineering Thermodynamics	
ENGN 1342	Groundwater Flow and Transport	
ENGN 1700	Fluid Mechanics of Aerospace and Energy Systems	
ENGN 1710	Heat and Mass Transfer	
ENGN 1860	Advanced Fluid Mechanics	
ENGN 1931P	Energy and the Environment	
ENGN 1931R	The Chemistry of Environmental Pollution	
ENGN 1932P	Sustainable Energy: Science and Technology	
ENGN 2911P	Fate and Transport of Environmental Contaminants	
Or any other course approved by the Concentration Advisor		
4. Capstone Design [3]		1
ENGN 1150	Environmental Engineering Design	
* 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 academic year 2021-22 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/)

Professional Track

The requirements for all undergraduate professional tracks within concentrations are standardized and additional information can be found here:

https://bulletin.brown.edu/undergradproftrack/

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 for or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

Materials Engineering Concentration Requirements

Materials engineers design, create, and manufacture materials which include semiconductors, polymers, ceramics, metal alloys, and composites. Their contributions have led to breakthroughs in many fields including computing, communications, automobiles, energy, aerospace, buildings/infrastructure, and biomedical devices. The Materials Engineering curriculum at Brown provides graduates with both the expertise necessary to practice their profession as well as the interdisciplinary foundation necessary to collaborate with the engineers who will use the materials that they develop. A substantial fraction of Materials Engineering students at Brown participate in research which allows them to make use of Brown's state-of-the-art facilities in microscopy, materials characterization, materials processing, and fabrication.

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 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/

Please note that all students concentrating in Engineering need to file a concentration declaration using the University's ASK advising system. This declaration must be first reviewed by the relevant Concentration Advisor and then approved by the Director of Undergraduate Studies after assuring compliance with all relevant program and accreditation requirements.

Standard Program for the Sc.B. degree

Mathematics Requirements

As mathematics is a cornerstone of all engineering programs, significant attention is given to early preparation in mathematics in engineering concentrations. It is recognized that students entering Brown will have different levels of mathematics preparation, and the following is offered as general guidance, though the actual choices of courses should be made in consultation with an exploratory advisor. MATH 0190 (or MATH 0100), followed by MATH 0200 (or MATH 0180) is the preferred sequence of courses to be taken in the freshman year. MATH 0100 and MATH 0180 offer content like that in MATH 0190 and MATH 0200, respectively, but the latter courses are highly recommended for future engineering students because they offer more examples of relevance to the field. Students who would prefer, or require, a more introductory level calculus course may start the sequence with MATH 0090. They may then take MATH 0200 (or MATH 0180) in the subsequent semester and in that case, would receive engineering concentration credit equivalent to that which they would have received having taken MATH 0190 and MATH 0200. However, students who find that the step up from MATH 0090 to MATH 0200 is too challenging, have a choice to take MATH 0190 (or MATH 0100) upon completion of MATH 0090, but in this case, MATH 0090 would not carry engineering concentration credit and the student would then need to take MATH 0200 (or MATH 0180) in the sophomore year.

Students who have taken Advanced Placement (AP) calculus courses in high school and/or have shown proficiency through AP examinations may start the calculus sequence at a higher-level than that suggested above. If a student has AP credit and accepts to use it, it then allows the student to place out of MATH 0190 (or MATH 0100). These students should enroll in the appropriate higher-level math course, e.g., MATH 0200 (or MATH 0180) or possibly MATH 0350 (a more theoretical course that covers similar material). Although it is impossible to place out of MATH 0200 or MATH 0350 with AP credit, we recognize that some students enter with an even higher level of preparation. Those students are advised to enroll in MATH 0520 (Linear Algebra), or MATH 0540 (Honors Linear Algebra), and take their second freshman mathematics course at a higher level, for example, MATH 1460 (Complex Analysis), MATH 1210 (Probability), or MATH 1220 (Mathematical Statistics). Alternatively, for some engineering concentrations, this second MATH credit requirement may be satisfied by taking a course from the Applied Mathematics Department, such as APMA 0350 (Applied Ordinary Differential Equations), APMA 0360 (Applied Partial Differential Equations), APMA 1650 (Statistical Inference) or APMA 1210 (Operations Research: Deterministic Models) if one of those courses listed is not taken for two APMA concentration credits. Details regarding the mathematics requirement for each concentration are listed in the corresponding programs.

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.

1. Core Courses:

ENGN 0030	Introduction to Engineering	1
or ENGN 0032	Introduction to Engineering: Design	
ENGN 0040	Engineering Statics and Dynamics	1
ENGN 0410	Materials Science	1
ENGN 0510	Electricity and Magnetism	1
ENGN 0520	Electrical Circuits and Signals	1
ENGN 0720	Thermodynamics	1
ENGN 0310	Mechanics of Solids and Structures	1
or ENGN 0810	Fluid Mechanics	
CHEM 0330	Equilibrium, Rate, and Structure	1
MATH 0190	Single Variable Calculus, Part II (Physics/Engineering)	1
or MATH 0100	Single Variable Calculus, Part II	
MATH 0200	Multivariable Calculus (Physics/Engineering)	1
or MATH 0180	Multivariable Calculus	
or MATH 0350	Multivariable Calculus With Theory	
APMA 0350	Applied Ordinary Differential Equations [1]	1
APMA 0360	Applied Partial Differential Equations I [1]	1
or MATH 0520	Linear Algebra	
or APMA 1210	Operations Research: Deterministic Models	
or APMA 1650	Introduction to Probability and Statistics with Calculus	
CHEM 0350	Organic Chemistry I	1
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	1
ENGN 1420	Kinetics Processes in Materials Science and Engineering	1
ENGN 1440	Mechanical Properties of Materials	1
PHYS 0790	Physics of Matter	1
or CHEM 0350	Organic Chemistry I	
or CHEM 1140	Physical Chemistry: Quantum Chemistry	
Three of the following: [2]		3
ENGN 1450	Properties and Processing of Electronic Materials	
ENGN 1470	Composite Materials	
ENGN 1475	Soft Materials	
ENGN 1480	Metallic Materials	
ENGN 1490	Biomaterials	
3. Capstone Design [3]		
ENGN 1000	Projects in Engineering Design I	1
or ENGN 1001	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 (https://engineering.brown.edu/undergraduate/concentrations/concentration-options/independent-study/)

Professional Track

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 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 for or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

Mechanical Engineering Concentration Requirements

The Sc.B. program in Mechanical Engineering (ME) has a long tradition of excellence at Brown. ME is one of the most versatile engineering disciplines as it explores a wide range of systems spanning fluids and solids. Students from this concentration learn the science of motion, designing and analyzing systems that shape our world: From high-precision nanomechanical machines to large-scale aerospace systems. At Brown, ME students carve unique paths leveraging computational, analytical, or experimental methodologies with other areas of interest in the spirit of the open curriculum. They become distinguished scholars, engineering innovators, and management leaders.

The curriculum in ME is intended to provide students with a broad interdisciplinary foundation complemented by specialized training in mechanical systems and fluid/thermal systems.

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/

Please note that all students concentrating in Engineering need to file a concentration declaration using the University's ASK advising system. This declaration must be first reviewed by the relevant Concentration Advisor and then approved by the Director of Undergraduate Studies after assuring compliance with all relevant program and accreditation requirements.

Standard Program for the Sc.B. degree

Mathematics Requirements

As mathematics is a cornerstone of all engineering programs, significant attention is given to early preparation in mathematics in engineering concentrations. It is recognized that students entering Brown will have different levels of mathematics preparation, and the following is offered as general guidance, though the actual choices of courses should be made in consultation with an exploratory advisor. MATH 0190 (or MATH 0100), followed by MATH 0200 (or MATH 0180) is the preferred sequence of courses to be taken in the freshman year. MATH 0100 and MATH 0180 offer content like that in MATH 0190 and MATH 0200, respectively, but the latter courses are highly recommended for future engineering students because they offer more examples of relevance to the field. Students who would prefer, or require, a more introductory level calculus course may start the sequence with MATH 0090. They may then take MATH 0200 (or MATH 0180) in the subsequent semester and in that case, would receive engineering concentration credit equivalent to that which they would have received having taken MATH 0190 and MATH 0200. However, students who find that the step up from MATH 0090 to MATH 0200 is too challenging, have a choice to take MATH 0190 (or MATH 0100) upon completion of MATH 0090, but in this case, MATH 0090 would not carry engineering concentration credit and the student would then need to take MATH 0200 (or MATH 0180) in the sophomore year.

Students who have taken Advanced Placement (AP) calculus courses in high school and/or have shown proficiency through AP examinations may start the calculus sequence at a higher level than that suggested above. If a student has AP credit and accepts to use it, it then allows the student to place out of MATH 0190 (or MATH 0100). These students should enroll in the appropriate higher-level math course, e.g., MATH 0200 (or MATH 0180) or possibly MATH 0350 (a more theoretical course that covers similar material). Although it is impossible to place out of MATH 0200 or MATH 0350 with AP credit, we recognize that some students enter with an even higher level of preparation. Those students are advised to enroll in MATH 0520 (Linear Algebra), or MATH 0540 (Honors Linear Algebra), and take their second freshman mathematics course at a higher level, for example, MATH 1460 (Complex Analysis), MATH 1210 (Probability), or MATH 1220 (Mathematical Statistics). Alternatively, for some engineering concentrations, this second MATH credit requirement may be satisfied by taking a course from the Applied Mathematics Department, such as APMA 0350 (Applied Ordinary Differential Equations), APMA 0360 (Applied Partial Differential Equations), APMA 1650 (Statistical Inference) or APMA 1210 (Operations Research: Deterministic Models) if one of those courses listed is not taken for two APMA concentration credits. Details regarding the mathematics requirement for each concentration are listed in the corresponding programs.

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.

1. Core Courses:		
ENGN 0030	Introduction to Engineering	1
or ENGN 0032	Introduction to Engineering: Design	
ENGN 0040	Engineering Statics and Dynamics	1
ENGN 0310	Mechanics of Solids and Structures	1
ENGN 0410	Materials Science [1]	1
ENGN 0510	Electricity and Magnetism	1
ENGN 0520	Electrical Circuits and Signals	1

ENGN 0720	Thermodynamics	1
ENGN 0810	Fluid Mechanics	1
CHEM 0330	Equilibrium, Rate, and Structure	1
MATH 0190	Single Variable Calculus, Part II (Physics/ Engineering)	1
or MATH 0100	Single Variable Calculus, Part II	
MATH 0200	Multivariable Calculus (Physics/ Engineering)	1
or MATH 0180	Multivariable Calculus	
or MATH 0350	Multivariable Calculus With Theory	
APMA 0350	Applied Ordinary Differential Equations [2]	1
APMA 0360	Applied Partial Differential Equations I [2]	1
CSCI 0111	Computing Foundations: Data	1
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	
2. Upper-Level Mechanical Engineering Curriculum: Complete at least 6 courses from the following groups:		**6**
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 and Mass Transfer	
Capstone: At least one course from the following must be taken in the final two semesters: [3]		
ENGN 1000	Projects in Engineering Design I	
or ENGN 1001	Projects in Engineering Design II	
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	
Robotic and Control Systems Electives: Up to two courses from:		
ENGN 1931Y	Control Systems Engineering	
Engineering Analysis and Computation Electives: Up to two courses from:		
ENGN 1840	Numerical Methods in Engineering	
ENGN 1950	Advanced Numerical Methods for Data, Simulation, and Optimization	
Energy and Environmental Engineering Electives: Up to two courses from:		
ENGN 1932P	Sustainable Energy: Science and Technology	
ENGN 1931P	Energy and the Environment	
Interdisciplinary Electives: Up to one course from: [4]		
ENGN 1620	Analysis and Design of Electronic Circuits	
or ENGN 1340	Water Supply and Treatment Systems - Technology and Sustainability	
or ENGN 1440	Mechanical Properties of Materials	
or ENGN 1470	Composite Materials	
or ENGN 1570	Linear System Analysis	
or ENGN 1931F	Introduction to Power Engineering	
or ENGN 1931Z	Interfaces, Information and Automation	
3. Upper Level, Advanced Science Course: At least one course from: [5]		**1**
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**

1 ENGN 1490 may be substituted if taken in Sophomore year.

2 Students who completed APMA 0330 and/or APMA 0340 prior to academic year 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.

Professional Track

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, 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 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 for or completing honors to the satisfaction of his/her research advisor and the Honors Program Committee.

Engineering and Physics Concentration Requirements

The program is designed to ensure that students take a significant portion of the usual curriculum in Engineering and 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 first and second years and then switch to this combined program. The Sc.B. degree program in Engineering and Physics is not accredited by ABET and is mostly intended to prepare students for graduate study in applied science and engineering. Since the requirements include both quantum mechanics with the physics concentrators and analog electronics with EE concentrators, as well as more mathematics than either Physics or Engineering, it is one of the more demanding programs at Brown.

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:		2
ENGN 0040 & ENGN 0030	Engineering Statics and Dynamics and Introduction to Engineering	
or ENGN 0031	Honors Introduction to Engineering	
or ENGN 0032	Introduction to Engineering: Design	
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)	1
or MATH 0100	Single Variable Calculus, Part II	
MATH 0200	Multivariable Calculus (Physics/ Engineering)	1
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.		3
CSCI 0111	Computing Foundations: Data	1
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
or PHYS 0470	Electricity and Magnetism	
ENGN 1690	Photonics Devices and Sensors	1
or PHYS 1510	Advanced Electromagnetic Theory	
PHYS 0500	Advanced Classical Mechanics	1
or ENGN 1370	Advanced Engineering Mechanics	
PHYS 1410	Quantum Mechanics A	1
PHYS 1420	Quantum Mechanics B	1
PHYS 1530	Thermodynamics and Statistical Mechanics	1
or ENGN 0720	Thermodynamics	
ENGN 1620	Analysis and Design of Electronic Circuits	1
CHEM 0330	Equilibrium, Rate, and Structure	1
or ENGN 0310	Mechanics of Solids and Structures	
or ENGN 0810	Fluid Mechanics	
or PHYS 1600	Computational Physics	
ENGN 0410	Materials Science	1
or ENGN 1560	Applications in Microwave Communications	
or PHYS 0560	Experiments in Modern Physics	
PHYS 1560	Modern Physics Laboratory	1
or 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:		1
PHYS 1990	Senior Conference Course	
or ENGN 1970	Independent Studies in Engineering	
or ENGN 1971	Independent Study in Engineering	
or ENGN 1972	Independent Study in Engineering Design	
or 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**

Entrepreneurship Certificate Requirements

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

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

Certificate Requirements

Core Courses:		2
ENGN 0090	Management of Industrial and Nonprofit Organizations	
ENGN 1010	The Entrepreneurial Process	
Elective Courses (choose two):		2
BIOL 2089	The Importance of Intellectual Property in Biotechnology	
CPSY 0220	Making Decisions	
ECON 1490	Designing Internet Marketplaces	
ECON 1730	Venture Capital, Private Equity, and Entrepreneurship	
ENGN 0020	Transforming Society-Technology and Choices for the Future	
ENGN 0610	Systems Thinking	
ENGN 0900	Managerial Decision Making	
ENGN 0930L	Biomedical Engineering Design and Innovation	
ENGN 1820	Future of Work	
ENGN 1931L	Biomedical Engineering Design and Innovation II	
ENGN 1931Q	Entrepreneurial Management in Adversity	
ENGN 1931W	Selling & Sales Leadership in the Entrepreneurial Environment	
ENGN 1932D	Qualitative Market Research for Entrepreneurs & Business Innovators	
ENGN 1932R	Leadership in Organizations ((formerly SOC 1260))	
ENVS 1207	Eco-Entrepreneurship (formerly UNIV 1207)	
ENVS 1545	The Theory and Practice of Sustainable Investing	
GNSS 1101	A Gender Perspective on Women and Enterprise	
IAPA 1201D	Social Entrepreneurship	
SOC 1118	Context Research for Innovation	
SOC 1260	Market Research in Public and Private Sectors	
URBN 1943	The Real Estate Development Process: An Entrepreneurial Lens	
Practicum:		1
ENGN 1931T	Entrepreneurship Practicum: Starting, Running, and Scaling Ventures	
Students must complete an Entrepreneurship Practicum (EP), an experiential semester course that enables them to apply what they have learned in the classroom to real-world projects. Students will apply the entrepreneurial process to a challenge or problem that is important to them, perhaps evolving from one of their other courses. The Practicum will act as a laboratory to identify and develop an impactful solution to that problem. [1]		
Total Credits		**5**

Biomedical Engineering - Master of Engineering Graduate Program

Requirements for Master of Engineering (Effective Fall 2025)

- Must complete a minimum of 8 tuition units.
  - no independent research credits
  - all 8 should be structured (non-independent study) advanced-level (1000 or 2000 level) courses
    - at least 3 courses in biological topics
    - at least 3 courses in engineering topics
- Must receive a grade of B or better, courses must be taken for a grade rather than credit/no credit.
- Time to completion can be less than two academic years depending on the preference of the student.

Biomedical Engineering - Master of Science Graduate Program

The Biomedical Engineering (BME) graduate program provides cutting-edge, interdisciplinary, graduate-level education at the interface of engineering, biology, and medicine. The program features an interdisciplinary approach in multiple complementary research areas: diagnostics, biomaterials, mechanobiology, regenerative engineering, and neuroengineering. Research in these areas is advancing fundamental biological, medical, and engineering knowledge while innovating to improve the human condition. The program is distinguished by its quantitative rigor and strong collaborative connections among academic science, clinical medicine, and industry. The BME graduate program is designed for students with backgrounds in engineering, physics, or applied mathematics that seek additional education and training in the field of biomedical engineering

For more information on admission and program requirements, please visit: http://www.brown.edu/academics/gradschool/programs/biomedical-engineering (http://www.brown.edu/academics/gradschool/programs/biomedical-engineering/) and https://www.brown.edu/academics/biomedical-engineering/academics/graduate-program (https://www.brown.edu/academics/biomedical-engineering/academics/graduate-program/)

Chemical Engineering Graduate Program

Five-year Bachelor of Science / Master of Science

Brown undergraduates in engineering and other quantitative concentrations may apply to enter an integrated program leading to a master of science degree completed in two semesters following the completion of their bachelor of science (Sc.B.) degree. The program requirements are identical to those of the regular Sc.M. degree programs, with the exception that 5th Year students are able to share up to two relevant 1000- or 2000-level Engineering courses between their bachelor's and master's programs. The maximum number of courses that can be transferred from the undergraduate program is two.

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)
- 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 (2000-level) mathematics/applied mathematics course.

- A three-course core in Chemical Engineering is taken which includes thermodynamics (ENGN 2730 or CHEM 2010), kinetics (ENGN 2750), and transport (typically ENGN 2760, ENGN 2911P, or ENGN 2810).
- The final three courses are electives or can be used for thesis preparation (ENGN 2980 Special Projects: Reading, Research, Design). Students should choose courses in consultation with the student's advisor to develop a coherent program. At least five of the eight courses must be at the 2000-level; up to three 1000-level courses may be taken where appropriate.
- 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 Chemical 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. **Deviations from these schedules can result in additional tuition.**

The program offers a non-thesis option in addition to the thesis option which does not require ENGN 2980.

PHYS 2020	Mathematical Methods of Engineers and Physicists	1
or ENGN 2010	Mathematical Methods in Engineering and Physics I	
ENGN 2020	Mathematical Methods in Engineering and Physics II	1
CHEM 2010	Advanced Thermodynamics	1
or ENGN 2730	Chemical and Environmental Thermodynamics	
ENGN 2750	Chemical Kinetics and Reactor Engineering	1
ENGN 2760	Heat and Mass Transfer	1
or ENGN 2911P	Fate and Transport of Environmental Contaminants	
or ENGN 2810	Fluid Mechanics I	
Three additional Engineering courses (At least five of the eight courses must be at the 2000-level; up to three 1000-level courses may be taken where appropriate.)		3
or ENGN 2980		
Total Credits		**8**

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:		2
ENGN 1750	Advanced Mechanics of Solids	
ENGN 2010	Mathematical Methods in Engineering and Physics I	
ENGN 2020	Mathematical Methods in Engineering and Physics II	
ENGN 2210	Continuum Mechanics	
ENGN 2220	Mechanics of Solids	
ENGN 2340	Computational Methods in Structural Mechanics	
ENGN 2410	Thermodynamics of Materials	
ENGN 2520	Pattern Recognition and Machine Learning	
ENGN 2810	Fluid Mechanics I	
ENGN 2820	Fluid Mechanics II	
ENGN 2912B	Scientific Programming in C++	
ENGN 2912V	Deep Learning for Scientists and Engineers	
ENGN 2605	Image Understanding	
ENGN 2790	Quantum Optics	
ENGN 2980	Special Projects, Reading, Research and Design	
ENGN 2930	Atomistic Modeling of Materials	
Two courses in Applied Mathematics, such as:		2
APMA 1690	Computational Probability and Statistics	
APMA 2070	Deep Learning for Scientists & Engineers	
APMA 2190	Nonlinear Dynamical Systems I	
APMA 2550	Numerical Solution of Partial Differential Equations I	
APMA 2560	Numerical Solution of Partial Differential Equations II	
APMA 2570B	Numerical Solution of Partial Differential Equations III	
APMA 2580A	Computational Fluid Dynamics	
APMA 2630	Theory of Probability I	
APMA 2822B	Introduction to Parallel Computing on Heterogeneous (CPU+GPU) Systems	
Two courses in data science/high performance computing		2
Two additional courses. To ensure depth these may be taken in Engineering, Applied Mathematics, Data Science, or other relevant disciplines.		2
Total Credits		**8**

For more information on admission and program requirements for the Data-Enabled Computational Engineering and Science program, please visit https://computational.engineering.brown.edu/

Please view sample course plans based on Sc.M. Thesis or Non-Thesis and Curriculum options at https://computational.engineering.brown.edu/program-and-schedule (https://computational.engineering.brown.edu/program-and-schedule/)

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		4
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

Electrical and Computer Engineering Graduate Program

Five-year Bachelor of Science / Master of Science

Brown undergraduates in engineering and other quantitative concentrations may apply to enter an integrated program leading to a master of science degree completed in two semesters following the completion of their bachelor of science (Sc.B.) degree. The program requirements are identical to those of the regular Sc.M. degree programs, with the exception that 5th Year students are able to share up to two relevant 1000- or 2000-level Engineering courses between their bachelor's and master's programs. The maximum number of courses that can be transferred from the undergraduate program is two.

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)
- 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 (2000-level) mathematics/applied mathematics course.
- Two additional 2000-level Engineering courses (other than ENGN 2980)
- Three additional Engineering or approved courses (not more than two 1000-level courses).
- One thesis preparation course (ENGN 2980 Special Projects: Reading, Research, Design).
- 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 Electrical and Computer 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. **Deviations from these schedules can result in additional tuition.**

The program offers a non-thesis option in addition to the thesis option which does not require ENGN 2980.

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 courses (not more than two 1000-level courses)		3
ENGN 2980	Special Projects, Reading, Research and Design	1
Total Credits		**8**

Environmental Engineering Graduate Program

Five-year Bachelor of Science / Master of Science

Brown undergraduates in engineering and other quantitative concentrations may apply to enter an integrated program leading to a master of science degree completed in two semesters following the completion of their bachelor of science (Sc.B.) degree. The program requirements are identical to those of the regular Sc.M. degree programs, with the exception that 5th Year students are able to share up to two relevant 1000- or 2000-level Engineering courses between their bachelor's and master's programs. The maximum number of courses that can be transferred from the undergraduate program is two.

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)
- 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 (2000-level) mathematics/applied mathematics course.
- A three-course core in environmental engineering is taken which includes thermodynamics (ENGN 2730, CHEM 2010), groundwater (ENGN 2342), and transport (typically ENGN 2911P), or other appropriate courses chosen in consultation with the advisor.
- The final three courses are electives (at least two at the 2000-level) or can be used for thesis preparation (ENGN 2980 Special Projects: Reading, Research, Design). 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 Environmental 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. **Deviations from these schedules can result in additional tuition.**

The program offers a non-thesis option in addition to the thesis option which does not require ENGN 2980.

PHYS 2020	Mathematical Methods of Engineers and Physicists	1
or ENGN 2010	Mathematical Methods in Engineering and Physics I	
ENGN 2020	Mathematical Methods in Engineering and Physics II	1
CHEM 2010	Advanced Thermodynamics	1
ENGN 2342	Groundwater Flow and Transport	1
ENGN 2911P	Fate and Transport of Environmental Contaminants	1

Three additional Engineering courses (at least one 2000-level and up to two ENGN 2980)		3
Total Credits		**8**

Materials Science and Engineering Graduate Program

Five-year Bachelor of Science / Master of Science

Brown undergraduates in engineering and other quantitative concentrations may apply to enter an integrated program leading to a master of science degree completed in two semesters following the completion of their bachelor of science (Sc.B.) degree. The program requirements are identical to those of the regular Sc.M. degree programs, with the exception that 5th Year students are able to share up to two relevant 1000- or 2000-level Engineering courses between their bachelor's and master's programs. The maximum number of courses that can be transferred from the undergraduate program is two.

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)
- 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 (2000-level) mathematics/applied mathematics course.
- Two advanced engineering courses recommended to be:
  - ENGN 2410 Thermodynamics of Materials or ENGN 1410 Physical Chemistry of Solids
  - ENGN 2420 Kinetic Processes and Mechanisms in Materials Science or ENGN 1420 Kinetics Processes in Materials Science and Engineering
- Two advanced engineering or science electives. Some recommended courses include:
  - ENGN 2430 Deformation Behavior of Materials or ENGN 1440 Mechanical Properties of Materials or ENGN 2490A Crystal Structures and Crystallography
  - ENGN 2210 Continuum Mechanics or ENGN 2240 Linear Elasticity
  - ENGN 2400 Electron Microscopy in Materials Science
  - ENGN 2930 Atomistic Modeling of Materials
  - ENGN 2460 Electronic and Magnetic Materials Design
  - ENGN 2920H Materials and Interfaces for Energy Storage Devices
- Two thesis preparation courses (ENGN 2980 Special Projects: Reading, Research, Design).
- 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 Materials Science and 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. **Deviations from these schedules can result in additional tuition.**

The program offers a non-thesis option in addition to the thesis option which does not require ENGN 2980.

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

Mechanical Engineering and Applied Mechanics Graduate Program

Five-year Bachelor of Science / Master of Science

Brown undergraduates in engineering and other quantitative concentrations may apply to enter an integrated program leading to a master of science degree completed in two semesters following the completion of their bachelor of science (Sc.B.) degree. The program requirements are identical to those of the regular Sc.M. degree programs, with the exception that 5th Year students are able to share up to two relevant 1000- or 2000-level Engineering courses between their bachelor's and master's programs. The maximum number of courses that can be transferred from the undergraduate program is two.

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)
- 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 (2000-level) mathematics/applied mathematics course.
- Two additional 2000-level Engineering courses (other than ENGN 2980)
- Three additional Engineering or approved science courses (not more than two 1000-level courses).
- One thesis preparation course (ENGN 2980 Special Projects: Reading, Research, Design).
- 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 Mechanical Engineering and Applied Mechanics 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. **Deviations from these schedules can result in additional tuition.**

The program offers a non-thesis option in addition to the thesis option which does not require ENGN 2980.

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

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.

Residential 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.		2
Total Credits		**8**

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.

Online 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.		2
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/

Sustainable Energy Graduate Program

The U.S. is undergoing an historic transition of its energy system in order to decarbonize and help mitigate the worst effects of global climate change. Optimistically, the electrical system will become largely based on renewable and sustainable sources in the next ten years, and major energy consumption sectors of transportation, residential and commercial buildings, and industrial production will electrify and approach net-zero carbon emissions around 2050. These controversial changes constitute complex transitions in economic, political, and regulatory alignments along with technological innovation and continuing scientific advances. There is an urgent and growing need for technically and scientifically literate practitioners who can join cross-disciplinary teams working in both the public and private sectors to craft transition pathways and help deploy sustainable energy systems. The Sc.M. in Sustainable Energy challenges students to integrate knowledge across a wide range of science, engineering, policy, and business topics, develop a focused expertise in one aspect of sustainable energy systems, and prepare to enter or re-enter a career path directly impacting the progress of electrification and decarbonization.

Core Courses (To be approved after program approval)

The core of the Sc.M. in Sustainable Energy is envisioned as 3 new required and customized 2000-level courses. One of these is structured as 2 “ristretto” mini-courses, each being a one-half-credit module. Together, these 3 courses aim to condense a large body of cross-disciplinary material into a cohesive foundation for would-be practitioners. In general, we are building a future-focused framework; not just collecting what is known today and practiced today, but instead positing pathways that conceptualize and exhibit how the energy system could evolve in the next 2-3 decades, driven by climate mitigation goals and technology investments. All students shall take all 3 courses, in the same sequence, at least initially.

ENGN 2XX1: Sustainable Energy Science and Technology (graduate enrollment in ENGN 1932P; Andrew Peterson, SoE). Students will learn the fundamental thermodynamics of energy conversions, as well as the tools to analyze energy technologies. The course will cover the basic science of greenhouse-gas induced climate change, and analyze energy technologies in terms of the trade-offs involved in emissions, cost, scalability, land use, and resource ability.

ENGN 2XX2A: Policy and Economics of Energy Transitions (Dr. Kathryn Chelminski, Lawrence Berkeley National Laboratory). This ½-credit module provides an intensive overview of the policy and economic processes involved in the clean energy transition, with examples drawn from the U.S. as well as the world. Technological feasibility is necessary but not sufficient for the successful decarbonization of energy systems. Empirical social science documents the political factors that matter for climate policy outcomes, such as special interest groups, costs to develop and deploy renewable energy systems, preferences for clean energy, and measures and perceptions of distributive justice associated with transitions. Through weekly readings from current research, policy, regulatory and other sources, students encounter a diverse set of perspectives and issues arising in the planning and implementation of energy projects and their technical and societal impacts. Weekly writing assignments require synthesizing key learnings, reviewing relevant regulatory docket orders, and connecting to the major concepts presented in class. Students will complete a final research paper including interviews with industry experts, or an essay exam based on class themes.

ENGN 2XX2B: Energy and Climate Systems Modeling (Dr. Jun Ukita Shepard, U.S. Department of Energy, Office of Policy). This ½-credit module examines global energy systems from a variety of technological and economic perspectives: technological transitions, renewable energy markets, climate science, and the complex relationship between energy consumption and climate change negotiations.

ENGN 2XX3: Electrification and Decarbonization (Rod Beresford, School of Engineering) Demand for electricity is surging and will continue to grow to as much as 2 or 3 times current capacity, as combustion energy sources are retired in favor of renewable sources in the transportation, buildings, and industrial sectors. Students will learn the fundamentals of the electrical grid in the U.S., including its history, ownership and regulatory structure, physics, and economics. The emphasis is on how the traditional and risk-averse focus on reliability and low cost can evolve in the decarbonization transition, expanding to target a smarter, more resilient, and more equitable set of societal goods.

Existing Engineering and Physical Science Courses

For their remaining 5 courses in the 1-year / 8-credit program, students shall select one focus area consisting of at least 3 related courses, with the remaining courses being free electives. In all cases, students consult with the Program Director in choosing from among existing Brown courses, including those comprising the following focus areas:

Energy Conversion Processes, Components, and Systems (at least 3 courses)

CHEM 1560N	Organometallic Chemistry	1
CHEM 1560S	The Chemistry of Polymeric Organic Materials	1
CHEM 1700	Nanoscale Materials: Synthesis and Applications	1
CHEM 2320	Solid State Chemistry	1
EEPS 2410	Kinetics of Geochemical Processes (Other 2000-level courses with approval)	1
ENGN 1130	Chemical Engineering Thermodynamics	1
ENGN 1931A	Photovoltaics Engineering	1
ENGN 1931P	Energy and the Environment	1
ENGN 2830	Compressible Fluid Flow	1
ENGN 2920H	Materials and Interfaces for Energy Storage Devices	1
PHYS 1530	Thermodynamics and Statistical Mechanics	1
PHYS 2140	Statistical Mechanics	1
PHYS 2410	Solid State Physics I	1
PHYS 2600	Computational Physics	1
Other 2000 level courses with approval		

Energy and Environment: Economics and Policy of Systems in Transition (At least 3 courses)

ECON 1110	Intermediate Microeconomics	1
or ECON 1130	Intermediate Microeconomics (Mathematical)	
ECON 1210	Intermediate Macroeconomics	1
ECON 1350	Environmental Economics and Policy	1
ECON 1355	Environmental Issues in Development Economics	1
ECON 1480	Public Economics	1
ECON 1490	Designing Internet Marketplaces	1
EEPS 1400	Climate Modeling I	1
EEPS 2410	Kinetics of Geochemical Processes	1
ENGN 2920H	Materials and Interfaces for Energy Storage Devices	1
ENGN 1931P	Energy and the Environment	1
POLS 1435	Politics of Climate Change	1
PHP 1730	Climate Risks and Health Solutions	1
PHP 1855	Infectious Disease Modeling	1
PHYS 2410	Solid State Physics I	1
PHYS 2600	Computational Physics	1
SOC 1315	Macro-Organizational Theory: Organizations in Social Context	1
SOC 2385	Environmental Sociology	1
Other 2000-level course with approval		

Technology Leadership Graduate Program

Requirements for the Master of Science in Technology Leadership for students admitted in Spring 2024

ENGN 2095	The Psychology of Decision Making	.5
ENGN 2800	Critical Challenge Project	1
ENGN 2040	Leadership Lab	.5
Total Credits		**2**

Courses

ENGN 0010. Introduction to Engineering: Design, Materials, and Structures.

The purpose of the course is to introduce students to the profession of engineering and the important role engineers play in society, as well as to provide a foundation for further study in engineering. The course begins with the consideration of engineering design and introduces a number of tools that are fundamental to engineering. These include vectors, computer aided design (CAD), and basic programming (Matlab). Particular attention is then focused on mechanics of materials and the analysis of static structures, but topics also include professional ethics and the social responsibility of engineers. Led by an undergraduate mentor/TA, students will complete three group design projects over the course of the semester related to the core course content. ENGN 0010 should be taken by students considering concentrating in engineering as well as students just curious about engineering and design.

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	25835	MWF	11:00-11:50(04)	(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	10285	MWF	9:00-9:50(09)	(D. Mittleman)
Fall	ENGN0030	S02	16987	MWF	9:00-9:50(09)	(Y. Qi)
Fall	ENGN0030	S03	16988	MWF	9:00-9:50(09)	(M. Gray)
Fall	ENGN0030	S04	16989	MWF	2:00-2:50(01)	(F. Goldsmith)
Fall	ENGN0030	S05	18473	MWF	2:00-2:50(01)	(I. Stuopis)
Fall	ENGN0030	S06	18474	MWF	2:00-2:50(01)	(I. Gonsher)
Fall	ENGN0030	C01	16991	T	9:00-10:20	(M. Laderer)
Fall	ENGN0030	C02	16992	T	9:00-10:20	(M. Laderer)
Fall	ENGN0030	C03	16993	T	10:30-11:50	(M. Laderer)
Fall	ENGN0030	C04	16994	T	10:30-11:50	(M. Laderer)
Fall	ENGN0030	C05	16995	T	1:00-2:20	(M. Laderer)
Fall	ENGN0030	C06	16996	T	1:00-2:20	(M. Laderer)
Fall	ENGN0030	C07	16997	T	2:30-3:50	(I. Stuopis)
Fall	ENGN0030	C08	16998	Th	9:00-10:20	(I. Stuopis)
Fall	ENGN0030	C09	18475	Th	9:00-10:20	(I. Stuopis)
Fall	ENGN0030	C10	18476	Th	9:00-10:20	(I. Stuopis)
Fall	ENGN0030	C11	18477	Th	10:30-11:50	(I. Stuopis)
Fall	ENGN0030	C12	18478	Th	10:30-11:50	(I. Stuopis)
Fall	ENGN0030	C13	19198	Th	1:00-2:20	(I. Stuopis)
Fall	ENGN0030	C14	19199	Th	1:00-2:20	(I. Stuopis)
Fall	ENGN0030	C15	19200	Th	2:30-3:50	(M. Laderer)

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).

ENGN 0040. Engineering Statics and Dynamics.
A broad introduction to Newtonian dynamics of particles and rigid bodies with applications to engineering design. Concepts include statics of structures; kinematics and dynamics of particles and rigid bodies; conservation laws; 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.

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	17005	Arranged	(G. Palmore)
Spr	ENGN0061	S01	25908	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	17006	Arranged	(G. Palmore)
Spr	ENGN0062	S01	25909	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	17008	TTh	1:00-2:20(06)	(T. Chaltas)
Fall	ENGN0090	S02	17009	TTh	2:30-3:50(12)	(T. Chaltas)

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

ENGN 0120A. Crossing the Consumer Chasm by Design.
Technologies have shaped human life since tools were sticks and flints to today's hydrocarbon powered, silicon managed era. Some spread throughout society; bread, cell phones, airlines, but most never do; personal jet packs, Apple Newton, freeze dried ice cream.

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

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

Enrollment limited to 18 first year students.

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 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 Atomistic 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 atomistic 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 0240. Biomedical Engineering Design and Innovation.
This course is an incubator for innovative ideas in biomedical design. Students across all disciplines are invited to collaborate with biomedical engineers to enhance the development of design solutions that address clinical and public health concerns. Students will form teams with their peers and a clinical advisor, identify and define a design project to meet a clinical need, and engage in the design process throughout the semester. Engineering concentrators should register for ENGN 1240.

Fall	ENGN0240	S01	18828	MW	8:30-9:50(09)	(A. Tripathi)

ENGN 0250. Biomedical Engineering Design and Innovation II.
This course is an incubator for innovative ideas in biomedical design. Students across all disciplines are invited to collaborate with biomedical engineers to enhance the development of design solutions that address clinical and public health concerns. Student teams formed in the previous semester will continue develop a design project based on an unmet clinical need with a clinical advisor, gaining hands-on process experience and generating innovative solutions. Engineering concentrators should register for ENGN 1250.

Spr	ENGN0250	S01	26626	MWF	11:00-11:50(04)	'To Be Arranged'

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 0040.

Fall	ENGN0310	S01	17011	MWF	9:00-9:50(09)	(D. Henann)
Fall	ENGN0310	C01	17012	T	9:00-10:20	(D. Henann)
Fall	ENGN0310	C02	17013	T	12:00-12:50	(D. Henann)

ENGN 0350. Art Fluid Engineering.
Art can be defined in many different ways, such as: Art is the action to produce objects with no practical use, whose only purpose is to be beautiful or stimulate the intellect in some way. Engineering, on the other hand, is a discipline that uses science to produce devices or processes that are intrinsically useful. We will combine two contrasting views to create objects with aesthetic value and can be useful. We will use fluid flows to create art. Discussions in which a ‘fluid’ idea is presented, and contrasting scientific/engineering and artistic analysis will be conducted. Students will identify a flow problem to create art: dynamic sculptures, paintings, videos, installations. Art pieces will be presented at the end of the semester and exhibited publicly. Engineering Students: Enroll in ENGN 1350 for advanced engineering credit with a prerequisite and scaled expectations.

Spr	ENGN0350	S01	25857	MWF	10:00-10:50(03)	(R. Zenit)

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

Fall	ENGN0410	S01	10283	TTh	2:30-3:50(12)	(L. Caretta)
Fall	ENGN0410	C01	17014	M	4:30-5:50	(L. Caretta)
Fall	ENGN0410	C02	17015	W	4:30-5:50	(L. Caretta)
Fall	ENGN0410	C03	17016	M	6:00-7:20	(L. Caretta)

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	17017	TTh	1:00-2:20(06)	(I. 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	10287	MWF	10:00-10:50(14)	(I. Stuopis)
Fall	ENGN0510	C01	17019	M	2:00-2:50	(J. Xu)
Fall	ENGN0510	C02	17020	W	2:00-2:50	(J. Xu)
Fall	ENGN0510	C03	17021	F	2:00-2:50	(J. Xu)

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.

Spr	ENGN0520	S01	20265	MWF	10:00-10:50(03)	(J. Rosenstein)

ENGN 0610. Systems Thinking.
Systems Thinking links theory and practice to better understand and improve the world around us. It examines the nature of systems in nature, society, and engineering, and applies interdisciplinary lenses to explore important global challenges like those tied to climate change, energy, health, and supply chains. This holistic approach provides both a strategic and practical means to visualize, analyze, and design solutions to improve performance. Students will engage in activities to discover how complex patterns of behavior can arise from simple structures and simple rules and draw on these insights to develop a deeper understanding of how people, process, and purpose align to get things done. In sum, this course helps students see systems in a whole new light, develop mental toolkits for analyzing tough issues, model their structure and behavior, and understand how and why change happens.

Fall	ENGN0610	S01	17022	MW	8:30-9:50(09)	(R. Morales)

ENGN 0620. Design Brief.
This course introduces students to the theory and practice of engineering design. Topics include conceptual frameworks that ground the design process, the application of engineering concepts to inform design decisions, visual and written representation and communication, and the practice of design engineering.

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.

Spr	ENGN0720	S01	20261	Arranged	'To Be Arranged'

ENGN 0810. Fluid Mechanics.
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, and drag. Vorticity and circulation. Navier-Stokes equation, applications. 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 PHYS 0070, APMA 0330 or APMA 0350 (can be concurrent).

Fall	ENGN0810	S01	17023	MWF	1:00-1:50(08)	(R. Zenit)
Fall	ENGN0810	C01	17024	T	1:00-2:20	(M. Martinez Wilhelmus)
Fall	ENGN0810	C02	17025	Th	1:00-2:20	(M. Martinez Wilhelmus)

ENGN 0860. Boat Building Design & Culture.
This course introduces the study of the design, engineering, work, material culture and history through the construction of a traditional workboat, a Maine Peapod. As the class builds the boat, we'll gain hands-on understanding of issues of engineering, design, skill, and workmanship. We will do historical research and visit museums to gain insight into the history of small craft and their builders/users from the nineteenth century to the present. Throughout the course, we will consider philosophical issues of tradition, creativity, and knowledge in engineering and making. Three longer writing assignments and an ongoing journal will connect hands-on work and research.

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

Spr	ENGN0900	S01	25836	TTh	10:30-11:50(09)	(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.

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

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

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

ENGN 0931L. Biomedical Engineering Design and Innovation II.
This course is an incubator for innovative ideas in biomedical design. Students across all disciplines are invited to collaborate with biomedical engineers to enhance the development of design solutions that address clinical and public health concerns. Student teams formed in the previous semester will continue develop a design project based on an unmet clinical need with a clinical advisor, gaining hands-on process experience and generating innovative solutions. Engineering concentrators should register for ENGN 1931L.

ENGN 1000. Projects in Engineering Design I.
Fall semester projects in design for concentrators in electrical, materials, and mechanical engineering. Students work in teams on projects that are defined through discussions with the instructor. An assembled product or detailed design description is the goal of the semester's effort. Students may elect to combine ENGN 1000 with ENGN 1001 to work on a year-long project with permission of the instructor. Students electing to pursue this option must take ENGN 1000 and ENGN 1001 in the same academic year, and must submit a project proposal no later than October 1. Permission of instructor is required. Applicants should fill out this form and attend the first class: https://forms.gle/Fkr8DYyaB2Gse9NZ6

Fall	ENGN1000	S01	17324	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 or detailed design description is the goal of semester's effort. Students may elect to combine ENGN 1000 with ENGN 1001 to work on a year-long project with permission of the instructor. Students electing to pursue this option must take ENGN 1000 and ENGN 1001 in the same academic year and must have submitted a project proposal by October 1 of the previous Fall semester. Permission of instructor is required. Applicants should fill out this form and attend the first class: https://forms.gle/Fkr8DYyaB2Gse9NZ6

Spr	ENGN1001	S01	25833	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	17341	TTh	10:30-11:50(13)	(D. Warshay)
Fall	ENGN1010	S02	18110	W	3:00-5:30(10)	(F. Slutsky)
Fall	ENGN1010	S03	18111	M	6:00-8:30PM	(J. Cohen)
Spr	ENGN1010	S01	25855	TTh	10:30-11:50(09)	(D. Warshay)

ENGN 1110. Transport and Biotransport Processes.
Aim: To develop a fundamental understanding of mass transport in chemical and biological systems. The course includes: mechanism of transport, biochemical interactions and separations; mass transport in reacting systems; absorption; membrane and transvascular transport; electrophoretic separations; pharmacokinetics and drug transport; equilibrium stage processes; distillation and extraction. Other features: design concepts; modern experimental and computing techniques; laboratory exercises. Prerequisites: APMA 0350.

Spr	ENGN1110	S01	20256	MWF	9:00-9:50(02)	(T. Raimondo)

ENGN 1120. Reaction Kinetics and Reactor Design.
Mechanisms, driving forces, and rate expressions of homogeneous and heterogeneous chemical and biochemical systems. Kinetics described from the potential energy surface to reaction networks. Basic concepts in reactor design and idealized reactor models. Chemostats and enzymatic reactors. Optimization. Temperature and energy effects in reactors. Catalysts and coupled transport effects. Prerequisite: ENGN 0720 or equivalent. Offered in alternate years.

ENGN 1130. Chemical and Statistical Thermodynamics.
Application and derivation of the laws of thermodynamics, built from the atomic scale up. Basic statistical mechanics treatment of chemical thermodynamics, and an in-depth treatment of the calculus of thermodynamics. Driving forces for atomic and macroscopic processes. Phase and chemical equilibria and partitioning of species in multiphase and reactive systems. Applications and examples drawn from chemical processing and environmental problems. Prerequisite: ENGN 0720 or equivalent. Offered in alternate years.

Fall	ENGN1130	S01	17313	TTh	10:30-11:50(13)	(J. Zeng)

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	26200	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	25847	TTh	6:40-8:00PM(18)	(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	20255	Arranged		'To Be Arranged'

ENGN 1220. Neuroengineering.
Course Goals: To develop an advanced understanding of how signals are generated and propagated in neurons and neuronal circuits, and how this knowledge can be harnessed to design devices to assist people with neurologic disease or injury. Fundamental topics in neuronal and neural signal generation, recording methods, and stimulation methods. Clinical/Translational topics include multiple clinically available and emerging neurotechnologies. Prerequisites: NEUR 0010 and ENGN 0510; or instructor permission, which may be provided after discussion with course faculty.

Spr	ENGN1220	S01	20252	Arranged		'To Be Arranged'

ENGN 1230. Instrumentation Design.
Sensors for pressure, temperature, blood flow, muscle and neural activity. Amplifiers, filters, and A/D-D/A converters. The use of computers in monitoring and controlling physiological processes. Feedback controllers for temperature, flow rate, and experimental stimuli. Intended as a design course primarily for biomedical engineers. Lab times to be arranged.

Fall	ENGN1230	S01	10276	MWF	10:00-10:50(14)	(D. Borton)

ENGN 1240. 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 0240.

Fall	ENGN1240	S01	18829	MW	8:30-9:50(09)	(A. Tripathi)

ENGN 1250. Biomedical Engineering Design and Innovation II.
This course is part two of the culmination "Capstone" of the biomedical engineering educational experience. The primary objective of this course is to recall and enhance design principles introduced through the engineering core curriculum and to apply this systematic set of engineering design skills to biomedical engineering projects. Student teams formed in the previous semester will continue develop a design project based on an unmet clinical need with a clinical advisor, gaining hands-on process experience and generating innovative solutions. For seniors only. Non-engineering concentrators should register for ENGN 0250.

Spr	ENGN1250	S01	26627	MWF	11:00-11:50(04)	(I. Wong)

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.

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

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

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	17316	TTh	9:00-10:20(05)	(L. Abriola)

ENGN 1350. Art Fluid Engineering.
Art can be defined in many different ways, but I like this one: Art is the action to produce objects with no practical use, whose only purpose is to be beautiful or stimulate the intellect in some way. Engineering is a discipline that uses science to produce devices or processes that are intrinsically useful. We will combine these two contrasting views to create objects that have aesthetic value and can be useful. This course aims to use fluid flows to create art. 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 semester.

Spr	ENGN1350	S01	25858	MWF	10:00-10:50(03)	(R. Zenit)

ENGN 1360. Soil Mechanics and Principles of Foundation Engineering.
Classification and identification of geological materials; mechanical and physical properties and methods of testing. Elements of the analysis of stress and strain in rock and soil masses; theories of failure, theory of seepage. Problems of building foundations; consolidation and settlement; stability of earth slopes and embankments. Includes geotechnical laboratory. Prerequisite: ENGN 0310.

ENGN 1370. Advanced Engineering Mechanics.
A unified study of the dynamics of particles, rigid bodies, and deformable continua. Generalized coordinates and Lagrange's equations; variational principles; stability of equilibrium; vibrations of discrete systems and of elastic continua, and wave propagation.

Spr	ENGN1370	S01	26214	W	3:00-5:30(10)	(K. Kim)

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 anaylsis (AFM, SEM, XPS, contact angle goniometry, ellipsometry, quartz crystal microbalance, electrochemistry, grazing angle IR); bulk analysis (DSC, mechanical testing) and biological analyis (bioassays, flourescence and confocal microscopy). Prerequisites: CHEM 0330, CHEM 0350, ENGN 0040 and BIOL 0200. Enrollment limited to 40.

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

Fall	ENGN1410	S01	10286	Th	4:00-6:30(04)	(A. Van De Walle)

ENGN 1420. Kinetics Processes in Materials Science and Engineering.
This course introduces the basic principles and formulations that describe kinetic processes in materials science and engineering. These are divided into the following principle types of mechanisms: solid state diffusion, reactions at surfaces and interfaces, and phase transformations. The final section of the course applies these principles to several relevant materials processing systems. Prerequisites: ENGN 0410, 0720, 1410 or equivalent.

Spr	ENGN1420	S01	20264	Arranged		'To Be Arranged'

ENGN 1440. Mechanical Properties of Materials.
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.

ENGN 1450. Properties and Processing of Electronic Materials.
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

Fall	ENGN1470	S01	18676	MWF	10:00-10:50(14)	(N. Padture)

ENGN 1475. Soft Materials.
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.

Fall	ENGN1490	S01	10277	MWF	2:00-2:50(01)	(K. Coulombe)

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.

Fall	ENGN1510	S01	10278	TTh	1:00-2:20(06)	(A. Shukla)

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

Spr	ENGN1520	S01	20249	TTh	9:00-10:20(05)	(K. Coulombe)

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, biomanufacturing, 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.

Spr	ENGN1550	S01	20254	Arranged		'To Be Arranged'

ENGN 1560. Applications in Microwave Communications.
We focus on the study/design of communications systems that operate within microwave frequencies (1-300 GHz). We review transmission/reception of TEM waves in various mediums, transmission lines, PCB's and waveguides. We look at RF components including oscillators, amplifiers, filters, tuners, frequency converters and antenna systems. We also measure system performance in terms of dynamic range, noise figure and power delivery. Once these foundations are set, we look at the End-2-End system design for Radio/TV, Radar, WIFI, 5G-Mobile, Satellites, and fiber optic networks. We also look at high-speed circuits used throughout the packet switched Internet. We look at practical design approaches for high-availability design with guest industry experts. We augment class lectures with biweekly P-sets and hands-on lab experiments, both with instrumentation and SW simulation. The class has 2 mid-terms, a class field trip, and final design project from class concepts.

Fall	ENGN1560	S01	10290	TTh	10:30-11:50(13)	(E. Tracy)

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	10291	MWF	1:00-1:50(08)	(L. Kozachkov)

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	20267	Arranged		'To Be Arranged'

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 junction fabrication in the cleanroom. Advanced topics, such as heterojunction bipolar transistors and silicon-on-insulator FETs, included in the graduate version.

Spr	ENGN1590	S01	20268	MWF	12:00-12:50(01)	(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.

Spr	ENGN1600	S01	25549	W	3:00-5:30(10)	(M. Saligane)

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	10295	Th	4:00-6:30(04)	(B. Kimia)

ENGN 1620. Analysis and Design of Electronic Circuits.
Analysis and design of a variety of fundamental analog integrated microelectronic circuits at the transistor level and their practical applications to sensing and interfacing in a range of fields; life sciences, wireless communications, and computing. Elementary device physics and circuit characteristics of semiconductor diodes and MOS field effect transistors (FETs) as fundamental building blocks will be discussed. Concepts of noise and fundamental limits of sensing will also be discussed. Required Text: Fundamentals of Microelectronics, Wiley, Behzad Razavi, any edition (1st - 3rd). Prerequisites: ENGN 0520 or ENGN 1230 or with instructor permission.

Spr	ENGN1620	S01	20269	Arranged		'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	10296	TTh	2:30-3:50(12)	(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 design area. Prerequisite: ENGN 1630 or passing of a quiz on basic digital logic concepts, or instructor permission.

Spr	ENGN1640	S01	20270	F	3:00-5:30(15)	(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	17026	TTh	1:00-2:20(06)	(E. Tracy)

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.

Fall	ENGN1690	S01	10297	TTh	10:30-11:50(13)	(A. Nurmikko)

ENGN 1700. High Reynolds Number Flows.
You will explore the fluid mechanics of aerospace and energy systems. Aerospace fluid dynamics are the dynamics of flows involving air. Such flows have a variable density over space and time. They can expand to take the shape of volume or be compressed into a confined space. These flows surround (air), inflate (air in lungs), compress (impact), hold/push (drag/thrust), and levitate (flight). Investigate flows to design and take advantage of their behavior for engineering solutions (e.g., extracting energy). Learn to identify a fluid and develop the framework (differential equations) describing compressible flow motion/dynamics. Study fundamental thin airfoil, wing, and boundary layer theory. Consider extracting energy from air flows using wind turbines. Solve the Euler equations using analysis and numerical methods. The course concludes by surveying advanced topics involving supersonics, hypersonics, and space propulsion. Prerequisites: ENGN 0720 and ENGN 0810.

Spr	ENGN1700	S01	25851	MWF	11:00-11:50(04)	(M. Rodriguez)

ENGN 1705. Sustainable Energy: Science and Technology.
The energy transition from fossil fuels to renewable sources may be the defining technological issue of the coming decades. This class covers the fundamental science and technology of energy technologies, focusing on emerging energy resources. Students will learn the fundamental thermodynamics of energy conversions as well as the tools to analyze energy technologies. The course will cover the basic science of the greenhouse-gas induced climate change, and will analyze energy technologies in terms of the trade-offs involved in emissions, cost, scalability, land use, and resource ability.

Fall	ENGN1705	S01	18204	MW	8:30-9:50(09)	(A. Peterson)

ENGN 1710. Principles of Heat Transfer.
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.

Spr	ENGN1730	S01	25550	MWF	1:00-1:50(06)	(D. Mittleman)

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.

Fall	ENGN1735	S01	17027	TTh	9:00-10:20(05)	(D. Harris)

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.

ENGN 1750. Advanced Mechanics of Solids.
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.

Fall	ENGN1750	S01	17028	TTh	10:30-11:50(13)	(V. Srivastava)

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.

ENGN 1790. 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

Spr	ENGN1790	S01	25551	M	3:00-5:30(13)	(D. Pacifici)

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?

ENGN 1820. Future of Work.
Technological advances have the potential to substantially change our work experiences, organizations and society. Collectively, these trends represent the Future of Work and can bring many positive benefits, such as new work options in the gig economy or new opportunities for start-ups. At the same time, such advances can raise ethical concerns and questions when technology is used to predict human behavior, replace employees, create a contingent and low-wage workforce, or drive autonomous vehicles, among many other examples. Using a combination of case studies, projects, academic articles, and current media materials, this class will examine three issues related to these new trends: How the world of work is changing, why these changes are important in relation to organizations and entrepreneurship, and what skills are necessary to shape the future of work in ways that are sustainable, ethical, and inclusive.

Spr	ENGN1820	S01	25844	T	4:00-6:30(16)	(B. Ozkazanc-Pan)

ENGN 1840. Numerical Methods in Scientific Computing.
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.

ENGN 1855. Design Principles and Process.
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.

ENGN 1860. Advanced Fluid Mechanics.
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.

Fall	ENGN1860	S01	17029	MWF	11:00-11:50(16)	(K. Breuer)

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

ENGN 1920. Sustainable Energy: Science and Technology.
The energy transition from fossil fuels to renewable sources may be the defining technological issue of the coming decades. This class covers the fundamental science and technology of energy technologies, focusing on emerging energy resources. Students will learn the fundamental thermodynamics of energy conversions as well as the tools to analyze energy technologies. The course will cover the basic science of the greenhouse-gas induced climate change, and will analyze energy technologies in terms of the trade-offs involved in emissions, cost, scalability, land use, and resource ability.

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. This course aims to empower students with theoretical and practical skills needed to design state-of-the-art biomedical optical systems, spanning from imaging systems to medical devices. Topics include ray transfer matrix analysis, use of symbolic and numerical computations, light as an electromagnetic wave, depth of field, diffraction, and imaging techniques such as widefield and scanning microscopy. By integrating a solid theoretical foundation with hands-on experience, this course offers an in-depth understanding of the topics, preparing students for optical device design challenges. Prerequisites: Undergraduate level ENGN 0510 Minimum Grade of S

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

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

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

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

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

ENGN 1930K. High-Performance Sensors and Mulitmedia.
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.

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.

ENGN 1930O. MicroElectroMechanical Systems (MEMS).
Integrated analysis and design of MicroElectroMechanical Systems (MEMS), which are highly integrated micron-scale devices used in many applications: sensors, energy (engines), optics, bioengineering, chemical processing, etc. Provides an introduction to the science and art of design, fabrication, performance, and use of MEMS in all disciplines of engineering.

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

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

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

ENGN 1930T. Aircraft Design.
The process of aircraft conceptual design as practiced in industry: requirements definition to initial sizing, configuration layout, analysis, sizing, optimization, and trade-off studies. Concepts and calculation methods for aerodynamics, stability and control, propulsion, structures, weights, performance, and cost; coverage of conventional and unconventional design methods drawing from knowledge gained in engineering science courses, synthesized towards novel imaginative aircraft designs guided by participants' interests. Prerequisite: the level of senior in engineering studies.

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

ENGN 1930W. The Art and Science of Light.
This studio course explores artificial light from both artistic and scientific perspectives. Laboratory demonstrations on optics and new light emitting materials will be counterbalanced by presentations on the historical and contemporary integration of these materials within the fields of architecture, industrial design, and sculpture. Students will be asked to reimagine the light bulb by developing artistic design alternatives to conventional lighting. Extensive outside work is expected. Written permission required.

ENGN 1930X. Entrepreneurship and New Ventures: A Socratic Approach to Innovation Analysis and Application.
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.
Overview of robots used in material handling, transportation and automated manufacturing. Sensors: force transducers, tachometers, orientation and joint angle detectors; video. Kinematics of a multidimensional robot arm. Inverse kinematics: optimal arm path generation. Automatic control: negative feedback, stability, proportional and integral compensation. Motor sizing, drive trains, navigation and locomotion. Labs: design and construction of a robot, with arm; use of embedded C programming for robot control. Enrollment limited to 24.

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.

Fall	ENGN1931A	S01	17093	M	3:00-5:30(03)	(D. Pacifici)

ENGN 1931C. Digital Nudges: Influencing Behavior in the Digital Age.
This seminar will explore the intersection of behavioral economics, psychology, and technology. It will delve into the concept of digital nudging, a strategy that uses small, non-intrusive cues to influence an individual's behavior in digital environments. This seminar provides participants with a deep understanding of digital nudges, their theoretical foundations, practical applications, and ethical considerations when building user experiences. By the end of the seminar, attendees will be well-equipped to analyze, design, and implement digital nudges while considering the ethical and psychological dimensions.

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

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

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

ENGN 1931H. Capital Formation & Financing Growth.
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 how, why, and when corporations return capital to shareholders; Assess the role, applicability, and issuance process of various debt and equity securities; Undertake a comprehensive valuation of a firm or project.

ENGN 1931I. Design of Robotic Systems.
Designing kinetic systems (i.e., systems requiring movement or motion) relies on both mechanical and electrical understanding. These systems include everything from mobile robots for rescue operation to electrically powered moving sculptures. Through a series of projects, students combine knowledge of electronic circuit design, sensors, actuators, motors, microcontrollers, control theory, and programming to build 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 1931K. Cell-Material Interactions in Tissue Engineering.
Students study how materials are used in cell-based biological applications focusing on engineered tissues and translational applications. Hybrid materials can be designed to elicit specific cellular interactions, including cell adhesion, mechanosensing, biochemical signaling, and electrical conduction. Primary scientific literature provides examples of design principles as applied to natural and synthetic materials in cell-based assays, engineered tissues, and in vivo implantation. Students participate in class discussions of scientific literature, lead discussion through oral presentation and group engagement, and write literature summaries including a final project (either a primary research manuscript or literature review). Pre Requisites: Recommended: Physiology/Cell & Molecular Biology, Biomaterials/Materials Science.

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

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

ENGN 1931N. Building Entrepreneurial Ecosystems for Economic Inclusion.
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.

ENGN 1931P. Energy and the Environment.
This course explores all the energy forms, but will focus on energy sources from which the majority of “useful” energy originates at the present time. Basic heat transfer problems related to energy efficiency are presented. Rankine and Brayton power cycles are introduced. Cycle modifications supporting energy efficiency are explored. Carbon footprint calculations are illustrated. Traditional and cutting-edge technologies for carbon capture and storage presented. Emissions such as SOx, NOx, and PM and their capture technologies investigated. The Earth climate model examined. The course features three 1-page long scientific summary writings and the tour to the Manchester Street Power Station.

Fall	ENGN1931FS01	17031	TTh	9:00-10:20(05)	(I. Kulaots)

ENGN 1931Q. Entrepreneurial Management in Adversity.
Companies get into trouble all the time -- making wrong products for the market, failing to meet sales quotas. This course examines actions a company must take in adverse conditions. There is never enough time to hire consultants, do research, hire new employees. Top Management must make decisions, often with insufficient data and alternative 'sub-optimal' options. Primary objectives are to understand analysis and rapid action when faced with adversity; identify the cause of adversity, building solutions to prevent reccurrence or give management the skills to solve problems; and develop recommendations and action plans to 'sell' to the Board of Directors.

Fall	ENGN1931(S01	18099	MW	10:00-11:20	(H. Anderson)

ENGN 1931R. The Chemistry of Environmental Pollution.
This course examines fundamental chemical aspects of pollutants and methods used to address pollution. We will consider pollution in air, water and soil media, and how pollution arises. Basic aspects of pollutant chemical partitioning will be explored. Examples of site investigation and the chemical tools used for that purpose will be discussed, along with risk assessment. Different ways of cleaning up contaminated sites will be examined, along with considering how mitigation and natural processes might represent options for addressing the particular pollution situation. Prerequisites are (MATH 0100, 0170, 0180, 0200, 0350 or 0190) and (CHEM 0100 or 0330).

Fall	ENGN1931F	S01	17315	MWF	11:00-11:50(16)	(E. Suuberg)

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 allies 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.

Fall	ENGN1931T	S01	18116	MW	8:30-9:50(09)	(A. Kohler)
Fall	ENGN1931T	S02	18254	TTh	1:00-2:20(06)	(A. Kohler)
Spr	ENGN1931T	S01	26242	TTh	1:00-2:20(08)	(A. Kohler)
Spr	ENGN1931T	S02	26243	MW	8:30-9:50(02)	(A. Kohler)

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.

Fall	ENGN1931V	S01	18105	MW	8:30-9:50(09)	(H. Anderson)

ENGN 1931X. Instrumentation for Research: A Biomaterials/Materials Project Laboratory.
This course is designed to prepare students for research in biomaterials/materials science by focusing on a project that yields a testable product/device. Advanced equipment/instrumentation will be used to fabricate and evaluate materials required for each project and to test the performance of the product/device that uses these materials. Example projects that illustrate the course plan include building a microfluidic-based medical sensor or fabricating a polymer-based battery. These 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 state-space and modern control theory. The course is open to all Engineering majors and will make use of existing simulation packages such as Matlab/Simulink.

Fall	ENGN1931Y	S01	10300	MTh	5:40-7:00	(A. Zaki)

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.

Fall	ENGN1932D	S01	18441	Th	4:00-6:30(04)	(A. Kingon)

ENGN 1932M. Foundations of Internet Communication Systems.
This course focuses on the foundational communications 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, etc. 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., routing and switching), 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. Our goal is to excite students to enter this amazing world of Communications Engineering.

ENGN 1932P. Sustainable Energy: Science and Technology.
The energy transition from fossil fuels to renewable sources may be the defining technological issue of the coming decades. This class covers the fundamental science and technology of energy technologies, focusing on emerging energy resources. Students will learn the fundamental thermodynamics of energy conversions as well as the tools to analyze energy technologies. The course will cover the basic science of the greenhouse-gas induced climate change, and will analyze energy technologies in terms of the trade-offs involved in emissions, cost, scalability, land use, and resource ability.

ENGN 1932R. Leadership in Organizations.
Leadership is an important part of organizational life and can be broadly understood as those behaviors and approaches that have the ability to influence ideas, actions, and outcomes in organizations and in society. In this course, we will examine different theories and approaches to leadership and then apply them in the context of inclusion and innovation. In today’s world, leading innovations in an inclusive way is important for the well-being of organizations/firms specifically and society broadly. Many different notions and practices of leadership co-exist, sometimes harmoniously and sometimes at odds with each other. Both technical and non-technical individuals must learn how to lead successfully in different contexts ranging from start-ups to well-established organizations across industries and sectors.

Fall	ENGN1932F	S01	17325	M	3:00-5:30(03)	(B. Ozkazanc-Pan)
Spr	ENGN1932R	S01	25845	F	3:00-5:30(15)	(B. Ozkazanc-Pan)

ENGN 1945. Immunoengineering.
The immune system is one of the most complex and powerful systems in the human body as it plays integral roles in maintaining homeostasis, wound healing, disease progression, chronic inflammation, autoimmunity, and cancer. Dysregulation of immune cells can cause disease progression; conversely, therapeutics capable of regulating immune cells can promote tissue regeneration or cancer cell killing. Immune engineering holds great potential for the development of therapeutics aimed at a broad range of diseases from autoimmunity to cancer and beyond. In this course, we will: (1) review key components of the immune system, (2) read and discuss primary research articles describing well-established and new immunotherapeutics, (3) discuss key concepts and laboratory techniques used in the design of immunotherapeutics, including strategies used to target drug delivery and design lipid nanoparticles, and (4) apply these concepts to design novel immune therapies.

Fall	ENGN1945	S01	18221	MWF	1:00-1:50(08)	(T. Raimondo)

ENGN 1950. Advanced Numerical Methods for Data, Simulation, and Optimization.
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. This course will present the mathematical theory of engineering optimization; review optimization theory and techniques from calculus; calculus of variations; necessary and sufficient conditions for optimality; bio-inspired engineering, optimal designs found in nature. Projects involving design and fabrication of optimal engineering systems will be encouraged.

ENGN 1970. Independent Studies in Engineering.
Independent Study in Engineering. Instructor permission required after submitting online proposal (https://forms.gle/PGBCzrcB2Y6N3Ca17). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

ENGN 1971. Independent Study in Engineering.
Independent Study in Engineering. Instructor permission required after submitting online proposal (https://forms.gle/PGBCzrcB2Y6N3Ca17). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

ENGN 1972. 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://forms.gle/PGBCzrcB2Y6N3Ca17). 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://forms.gle/PGBCzrcB2Y6N3Ca17). Section numbers vary depending on concentration. Please check Banner for the correct section number and CRN to use when registering for this course.

ENGN 2001. Strategic Planning.
The approach this course shall take is in understanding the various tools used to plan when the future is less than certain. The course is centered around the scenario planning method, incorporating other tools such as nominal group technique, the Delphi Method, and Set-Based Design. The key learning outcome is to gain an understanding of how strategic planning, regardless of tool, is ultimately about building consensus across the organization, to communicate strategically in order to act strategically.

ENGN 2002. Climate Solutions: Science and Society.
This course is designed to introduce you to the most recent science of climate change and its impacts in the coming decades, and will focus on solutions (technical, social, political, and economic) that are being or could be implemented to avert the worst consequences of this human caused problem. The course discusses the scientific foundation for a goal of net zero greenhouse gas emissions, and then explores how this might be achieved, and how different theories of change, equity and justice might lead to different conceptions of what an optimal solution might look like. The final deliverable asks your team to assess a climate solution in your industry and the barriers to, and opportunities for, more rapid implementation of that solution.

ENGN 2010. Mathematical Methods in Engineering and Physics I.
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	10301	MTh	7:10-8:30PM	(A. Zaki)

ENGN 2020. Mathematical Methods in Engineering and Physics II.
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	20271	TTh	9:00-10:20(05)	(A. Peterson)

ENGN 2031. Communication and Influence.
Communication skills impact success. Everyone can improve their communication skills. In this course, you will learn about the theories of communication, have multiple practice opportunities and receive individualized coaching. We will address both in-person and virtual communication. We will focus on persuasive communication, including verbal and nonverbal communication, the relationship between a presenter's goal and the goals/perspectives of their audience, and the classical rhetorical elements of logos, ethos and pathos. You will also learn how to create compelling business presentations. This course also includes persuasive written communication. The written component will focus on short-form communication such as Slack and emails. PowerPoint presentation best practices will also be addressed.

Fall	ENGN2031	S01	17943	Arranged	(B. Tannenbaum)

ENGN 2040. Leadership Lab.
Leadership is a critical piece of the student experience for the Master of Technology Leadership (MTL). Designed as an integrated application, it spans the length of the program and is woven into the fabric of the other courses. In both residential and online settings, students will engage in discussions, reflections, lectures, simulations and experiential activities focused on their professional development as leaders. Students will be consistently challenged to apply the leadership theory and practice they are exploring in the program to their MTL team and personal work environment. They will also have opportunities to establish professional development goals and receive support from peers and faculty relative to those aspirations. By the end of the course, students should have improved their leadership skills and be confident in their ability to assume greater levels of responsibility.

ENGN 2080. Emerging Technologies and Innovation Ecosystems.
Technological trends and marketplace derive 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. The Psychology of 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 2097. The Psychology of Decision Making: Advanced Topics.
This course is a follow-on to The Psychology of Decision Making (ENGN 2095). It focuses on elaborating and developing the nuances and limitations associated with the topics covered in that course. We will review topics in judgment and decision making 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 2098. Leading Innovation Strategy.
Today's leaders not only have to have the leadership skills to navigate complex and volatile business environments, they will also need to implement effective innovative strategies to move businesses forward. In the context of rapid technological advancements and digital transformations, developing an effective innovation strategy can propel organizations to stay competitive and find growth opportunities in a global context. Such innovation derives from strong entrepreneurial leadership and an understanding of the capabilities and strategic objectives of one's organization. It also requires an understanding of the innovation ecosystem within particular industries and foresight to strategically take advantage of opportunities. This class will focus on developing the necessary skills and strategies for individuals to succeed as innovation leaders.

Spr	ENGN2098	S01	25843	Arranged	(B. Ozkazanc-Pan)

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.

ENGN 2125. Engineering Management + Decision Making.
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.

Fall	ENGN2150	S01	17342	M	9:00-12:00	'To Be Arranged'
Fall	ENGN2150	S02	18488	T	3:00-6:00	'To Be Arranged'
Fall	ENGN2150	S03	18489	W	6:00-9:00PM	'To Be Arranged'

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.

Fall	ENGN2160	S01	17327	M	3:00-6:00	'To Be Arranged'
Fall	ENGN2160	S02	18115	W	3:00-6:00	'To Be Arranged'
Fall	ENGN2160	S03	18490	Th	12:00-3:00	'To Be Arranged'

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.

Fall	ENGN2171	S01	17322	TTh	8:30-12:30	(L. Manfredi)

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 broad 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.

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 2190. Financial Management.
This course focuses on core concepts related to financial management.

ENGN 2191. Strategic Management.
This course focuses on core concepts related to strategic management.

ENGN 2192. Ethical Dilemmas in Technology Leadership.
The course shall explore relevant ethical frameworks of history, looking at the particular interplay between ethics and technology. As we move through the elements of an ethical dilemma’s lifecycle, we will learn how to spot a dilemma in the making, the ways in which these dilemmas may have been prevented, and how leaders can arm themselves to make ethical choices in their own careers.

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.
An introduction to the mathematical foundations of continuum mechanics. Vectors and tensors, properties and basic operations. Kinematics of deformation. Conservation laws, thermodynamics. Stress. Constitutive equations. Elastic, viscous, and viscoelastic response. Linearization. Simple problems in finite and linear elasticity, and in Navier-Stokes flows. Creep and relaxation in linear viscoelasticity.

Fall	ENGN2210	S01	17347	MWF	2:00-2:50(01)	(K. Kim)

ENGN 2220. Mechanics of Solids.
A unified introduction to the engineering mechanics of elastic, plastic, and time-dependent solid materials and structures. Stress and equilibrium. Kinematics of deformation, strain, and compatibility. Tensor representation and principal values. Principle of virtual work. Formulation of stress-strain relations in elasticity, plasticity, and viscoelasticity. Uniqueness. Extremum and minimum principles, including energy methods.

Spr	ENGN2220	S01	25837	TTh	9:00-10:20(05)	(D. Henann)

ENGN 2240. Linear Elasticity.
General theorems in linear elasticity. Basic singular solutions. Boussinesq-Papkovich and Galerkin representations. Curvilinear coordinates. Cavity, inclusion, crack and contact problems. States of plane strain, plane stress, and axial symmetry. Complex variable techniques. Torsion. Thermoelasticity.

ENGN 2260. Stress Waves in Solids.
Elastic wave propagation theory with an introduction to waves in viscoelastic and plastic media. Waves in unbounded media, half spaces, layered media, plates, rods, and beams. Solutions to transient problems. Relation of theory to experiment. Stress waves and fracture.

ENGN 2270. Advanced Elasticity.
Large elastic deformation. Controllable deformations of incompressible materials. Initial stress problems. Elastic stability. Additional topics may include membrane theory, fiber-reinforced materials, second-order 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	25838	MWF	2:00-2:50(07)	'To Be Arranged'

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

ENGN 2340. Computational Methods in Structural Mechanics.
Fundamentals of the finite element method of structural analysis. Nodal points, element design, and consistent formulation for assumed functions. Principle of virtual work, formulation of element stiffness and master stiffness matrices. Relation to variational and minimum principles. Linear elastic analysis for static problems; direct and iterative procedures. Nonlinear static analysis with piecewise linearization; elastic-plastic behavior, large geometry changes. Time dependent behavior.

Fall	ENGN2340	S01	17345	MW	4:30-5:50(03)	(Y. Bazilevs)

ENGN 2342. 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	ENGN2342	S01	17317	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	17348	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 sold mechanics, theory of optimal design, shell structures and instability, or other topics of interest to the staff or visitors.

ENGN 2380. Fracture Mechanics.
The mechanics of brittle and ductile fracture in structural materials. Elastic stress fields near cracks, theories of brittle fracture, elastic fracture mechanics. Techniques of stress analysis. Elastic-plastic analysis of crack extension. Plastic instability. Fatigue, creep, and dynamic fracture. Dislocation mechanisms, cleavage, ductile fracture by void growth. Transitional behavior, rate sensitivity, running cracks. Fracture toughness and fatigue testing and structural design considerations.

Spr	ENGN2380	S01	26213	M	3:00-5:30(13)	(H. Kesari)

ENGN 2400. Electron Microscopy in Materials Science.
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	25846	MWF	10:00-10:50(03)	(D. Paine)

ENGN 2410. Thermodynamics of Materials.
Conditions for equilibrium and stability. First and higher order phase transformations. Critical phenomena. Order-disorder transitions. Principles of phase diagram calculation and construction for binary and ternary phase diagrams. Solution models. Chemical reactions for gases and pure phases. Thermodynamics of surfaces and interfaces. Statistical thermodynamics with representative applications.

Fall	ENGN2410	S01	17343	TTh	1:00-2:20(06)	(D. Paine)

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.

Spr	ENGN2420	S01	20260	MWF	1:00-1:50(06)	(E. Chason)

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.

ENGN 2450. Exchange Scholar Program.

Fall	ENGN2450	S01	16680	Arranged		'To Be Arranged'	

ENGN 2460. Electronic and Magnetic Materials Design.
This course combines materials chemistry and condensed matter physics to understand the design of nanoscale electronic and magnetic devices. This course integrates fundamental atomistic understanding, heterostructure design, and macroscopic properties. We will learn and apply knowledge of chemistry, crystallography, defects, deposition, and device physics to delve into thin film materials used in fuel cells, solid state sensors, quantum information science, logic and memory, and data storage. We will not only study examples used today, but also explore cutting-edge research on the frontier of these areas. Our goal is to better understand the functional materials and heterostructures used in solid states devices. The course is intended to support graduate students conducting research in nanoscale devices.

Spr	ENGN2460	S01	25828	W	3:00-5:30(10)	(L. Caretta)

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	18096	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.

Spr	ENGN2500	S01	26201	W	3:00-5:30(10)	(B. Kimia)

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.

ENGN 2520. Pattern Recognition and Machine Learning.
This course will cover fundamental concepts in pattern recognition and machine learning. We will focus on mathematical formulations and computational methods that are broadly applicable. Topics include supervised learning, parametric and non-parametric models, decision theory, bayesian inference, dimensionality reduction, clustering, feature selection, generalization bounds, support vector machines and neural networks. We will consider motivating applications in computer vision, signal processing, medical diagnostics, and information retrieval.

Spr	ENGN2520	S01	20272	Arranged		'To Be Arranged'	

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 open-ended 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 2560. Computer Vision.
Fundamentals of Computer Vision with an emphasis on multiview geometry and drone imaging. Camera models, Camera calibration, epipolar geometry, essential and fundamental matrices, relative pose estimation, RANSAC, two-view and multiview triangulation, 3D reconstruction, bundle adjustment, Levenberg-Marquardt, absolute pose estimation (PnP/EPnP), drone flight operation and image acquisition, feature-based Visual Odometry (VO), Optical Flow, Direct VO, Simultaneous Localization and Mapping (SLAM), Stereo and Multiview Stereo, pose averaging, trifocal pose estimation, Image-Based Localization (IBL), edge/curve-based odometry, RGBD cameras (Microsoft Kinect, Intel RealSense), surface reconstruction and modeling.

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.

Spr	ENGN2590	S01	20274	MWF	12:00-12:50(01)	(A. Zaslavsky)

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.

Fall	ENGN2605	S01	18083	Th	4:00-6:30(04)	(B. Kimia)

ENGN 2620. Solid State Quantum and Optoelectronics.
Incorporates the study of interaction of radiation with matter emphasizing lasers, nonlinear optics, and semiconductor quantum electronics. Q-switching and mode-locking, electro- and acousto-optic interactions, harmonic generation and parametric processes, self-focusing and phase modulation, stimulated Raman and Brillouin scattering, ultrashort pulse generation, nonlinear processes of conduction electrons in semiconductors, bulk and surface polaritons. Prerequisite: ENGN 2600 or equivalent.

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 in experimental optics techniques and basic microscopy.

Fall	ENGN2625	S01	10302	MW	10:00-11:20(14)	(K. Toussaint)

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

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

ENGN 2660. Physics and Technology of Semiconductor Heterostructures.
Covers, largely from an experimental point of view, topics of current interest in semiconductor heterostructure physics and technology; magentotransport 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.

Fall	ENGN2660	S01	17094	TTh	2:30-3:50(12)	(A. Zaslavsky)

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 (PHYS 1530) is required. We will use scaling arguments and simple physical pictures as much as possible.

ENGN 2702. Descriptive Analytics for Technology Leaders.
Acquiring, enriching, and analyzing data for business analytics is an essential use case for technology in business enterprises. This course helps prepare students for management roles that oversee the transformation of business data into actionable information, including how to communicate insights through visualizations. Such roles are ubiquitous in modern enterprises that use data analytics, business intelligence, and data science teams. The course opens with a series of interlocking frameworks that businesses use to take a problem—any problem—and break it down into components that can be analyzed with the use of diverse data sources and analytical approaches. Students then practice using two widely available tools, Excel and Tableau Desktop, to tackle these analyses and solve problems with real-world data sets. This work teaches students to integrate and transform data, analyze the data, and create appropriate visualizations/summaries/results/insights.

Fall	ENGN2702	S01	18258	Arranged	(A. Braff)

ENGN 2703. Entrepreneurial Thinking.
In the context of global competition and rapid technological advancements, developing entrepreneurial leadership skills can propel individuals and organizations to develop innovations and find growth opportunities. Such leadership derives from a strong entrepreneurial mindset that includes finding unmet needs, being resilient under conditions of uncertainty and having a propensity to seek creative, learning opportunities. These leadership skills are necessary given that many businesses now require digital transformation to thrive in the age of technological disruptions.

Fall	ENGN2703	S01	17326	Arranged	(B. Ozkazanc-Pan)

ENGN 2704. Predictive Analytics.
This course, which builds on the analytical skills developed in Descriptive Analytics, is a deep dive into the predictive analytics techniques that underpin strategic decision-making in contemporary business environments. Students will engage in event forecasting, participating in an in-class forecasting contest designed to put theory into practice. A key component of the course is exploration of Bayes' Theorem, providing a probabilistic foundation for making informed predictions. The course covers time-series forecasting of business metrics and customer-level predictive modeling techniques, enabling students to anticipate customer behaviors and take action at scale. This work segues into calculating customer lifetime value, a vital metric for evaluating long-term business relationships and profitability, along with customer experience analytics. It incorporates the latest advances in generative AI, examining its application to data analytics and its potential to revolutionize the way businesses analyze, visualize, and forecast trends.

ENGN 2705. Sustainable Energy: Science and Technology.
The energy transition from fossil fuels to renewable sources may be the defining technological issue of the coming decades. This class covers the fundamental science and technology of energy technologies, focusing on emerging energy resources. Students will learn the fundamental thermodynamics of energy conversions as well as the tools to analyze energy technologies. The course will cover the basic science of the greenhouse-gas induced climate change, and will analyze energy technologies in terms of the trade-offs involved in emissions, cost, scalability, land use, and resource ability.

Fall	ENGN2705	S01	18205	MW	8:30-9:50(09)	(A. Peterson)

ENGN 2706. Electrification and Decarbonization.
Decarbonization depends on electrification coupled with conversion to renewable sources of electricity generation. Students will learn the fundamentals of the electrical grid in the U.S. including its history, ownership and regulatory structure, physics, and economics. The emphasis is on how the traditional and risk-averse focus on reliability and low cost can evolve in the decarbonization transition, expanding to target a smarter, more resilient, and more equitable set of societal goods. Hands-on skills will be gained through several open-source modeling tools applied to grid modernization projects and case studies. Major topics include optimization in energy systems; the physics of the electric grid; centralized power transmission and distribution systems; distributed energy resources, including storage and microgrids; reliability, resilience, energy burden, and equity; and evolving power system business models and electricity market issues.

ENGN 2707. Policy and Economics of Energy Transitions.
An intensive overview of the policy and economic processes involved in the clean energy transition with examples drawn from the U.S. as well as the world. Technological feasibility is necessary but not sufficient for the successful decarbonization of energy systems. Empirical social science documents the political factors that matter for climate policy outcomes, such as special interest groups, costs to develop and deploy renewable energy systems, preferences for clean energy, and measures and perceptions of distributive justice associated with transitions. Students will encounter a diverse set of perspectives and issues arising in the planning and implementation of energy projects and their technical and societal impacts.

Spr	ENGN2707	S01	26638	F	3:00-5:30(15)	'To Be Arranged'

ENGN 2708. Energy Modeling for Policymaking.
Overview of energy systems and climate modeling for policymaking and application of fundamental concepts to emerging policy areas. The course will begin with lecture deep dives into key modeling concepts and models and then moves into hands-on evaluations of policies to accelerate the deployment of low-carbon energy technologies.

Spr	ENGN2708	S01	26637	Th	4:00-6:30(17)	'To Be Arranged'

ENGN 2709. Electrification and Decarbonization.
Decarbonization depends on electrification coupled with conversion to renewable sources of electricity generation. Students will learn the fundamentals of the electrical grid in the U.S. including its history, ownership and regulatory structure, physics, and economics. Emphasis is on how the traditional and risk-averse focus on reliability and low cost can evolve in the decarbonization transition, expanding to target a smarter, more resilient, and more equitable set of societal goods. Hands-on skills will be gained through several open-source modeling tools applied to grid modernization projects and case studies. Major topics include optimization in energy systems; the physics of the electric grid; centralized power transmission and distribution systems; distributed energy resources, including storage and microgrids; reliability, resilience, energy burden, and equity; and evolving power system business models and electricity market issues. Open to Seniors who have taken ENGN 0510 and ENGN 0520.

ENGN 2730. Chemical and Environmental Thermodynamics.
This is a fundamentals course targeted at first or second-year graduate students in chemical engineering, environmental engineering or related fields. The course reviews and expands on the principles of chemical thermodynamics: equilibrium criteria, fundamental relations, derivation of property relations, phase equilibrium, mixture behavior, intermolecular interactions, and reaction networks. The course will also cover the thermodynamic aspects of electrochemical systems, surface phenomena, complex molecules, and self-assembly, and will incorporate an introductory entryway module on statistical mechanics. The fundamental principles will be illustrated through application to current research topics in chemical technologies and environmental systems. Designed for students with some prior thermodynamics coursework. Undergraduates with thermodynamic background may enroll with instructor permission.

Fall	ENGN2730	S01	17318	TTh	9:00-10:20(05)	(R. Hurt)

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

Fall	ENGN2735	S01	18094	TTh	9:00-10:20(05)	(D. Harris)

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

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

Fall	ENGN2750	S01	17314	MWF	11:00-11:50(16)	(F. Goldsmith)

ENGN 2760. Heat and Mass Transfer.
Convection. Laminar flow: boundary layer equations and similarity solutions; solution techniques for arbitrary wall temperature distribution; development of flow in tubes. Turbulent flow: semiempirical methods of solution for turbulent shear layers. Natural convection. Separated flow. Condensation and evaporation. Fundamentals of heat and mass transfer for chemically reacting flows. Radiation. Basic concepts and properties of solids and gases.

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.

Spr	ENGN2790	S01	25552	M	3:00-5:30(13)	(D. Pacifici)

ENGN 2800. Critical Challenge Project.
The Critical Challenge Project (CCP) is an integrative experience in the Master's in Technology Leadership curriculum. Through the project, students address a critical organizational challenge, drawing from their own professional experiences, their MTL coursework, and career aspirations. In collaboration with their CCP mentors and peers, students analyze their chosen critical challenges from multiple perspectives, with insights developed throughout the program, and create comprehensive plans for addressing the challenges.

Fall	ENGN2800	S01	17340	Arranged		(L. Leventon)

ENGN 2801. Visual Storytelling.
Data visualization is an essential tool for both discovering and communicating key data findings. However, it's easy to underestimate the visual polish that goes into creating effective presentation-level graphics. This course will act as a technical primer for building data visualizations in Microsoft Excel and Adobe Illustrator, but the core focus will be the graphic design decisions – color, hierarchy, font selection, labeling – that can elevate a graphic into something truly coherent, unique and memorable.

Fall	ENGN2801	S01	18259	Arranged		(R. Fischer-Baum)

ENGN 2810. Fluid Mechanics I.
Formulation of the basic conservation laws for a viscous, heat conducting, compressible fluid. Molecular basis for thermodynamic and transport properties. Kinematics of vorticity and its transport and diffusion. Introduction to potential flow theory. Viscous flow theory; the application of dimensional analysis and scaling to obtain low and high Reynolds number limits.

Fall	ENGN2810	S01	17321	MWF	11:00-11:50(16)	(M. Rodriguez)

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.

Spr	ENGN2820	S01	25841	MWF	11:00-11:50(04)	(M. Martinez Wilhelmus)

ENGN 2830. Compressible Fluid Flow.
We explore the fluid mechanics of aerospace and energy systems in this course. Aerospace fluid dynamics are dynamics of flows involving air. Such flows have variable density over space and time. They can expand to take the shape of their volume or be compressed into an enclosing, confined space. These flows surround (air), inflate (air in lungs), compress (impact), hold/push (drag/thrust), and levitate (flight) us. We investigate flows to design and take advantage of their behavior for engineering solutions (e.g., extracting energy). You will learn to identify a fluid and develop the mathematical framework (differential equations) that describe compressible flow motion/dynamics. We study fundamental thin airfoil, wing, and boundary layer theory. We will consider extracting energy from air flows using wind turbines. We conclude by surveying advanced topics involving supersonics, hypersonics, and space propulsion.

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 classes focuses on advanced computer architecture concepts, including super-scalar processor design, out-of-order execution, branch prediction, multi-core processors, memory hierarchy consistency, GPU architectures, and architecture of large-scale systems such as data centers and supercomputers. Class work expected to include HWs, Labs, and projects. Prerequisite: ENGN 1640 or permission of instructor.

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

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

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

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

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

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

Spr	ENGN2910(	S01	20257	F	3:00-5:30(15)	(A. Tripathi)

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

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

ENGN 2910J. Mechanics and Surface Science of Nanostructures.
Thermodynamics ideas applied to surfaces - surface energies and crystal shapes, concepts of surface stress and stiffness. Surface processes in epitaxial growth. Morphological stability and evolution of surface based nanostructures. Atomistic approaches to surface energetics and kinetics. Elastic interactions of defects on surfaces. Strain driven self-assembly. Surface processes in thin film electronic devices.

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,NσT) and non-equilibrium properties. Simulations with three-body potentials and EAM potentials. Molecular statics. Introduction to quantum mechanical methods, Application to the above methods to defect interactions in solids, structure of surfaces, crystal growth and structure of nanostructures.

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

ENGN 2910Q. 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

Fall	ENGN2910S	S01	10282	MWF	1:00-1:50(08)	(I. Wong)

ENGN 2910T. Physics of Materials.
No description available.

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

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

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

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

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

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

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

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

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

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

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

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

ENGN 2911H. Computer Architecture.
No description available.

ENGN 2911J. Computational Electromagnetics.
This course will introduce numerical techniques for solving practical and theoretical problems in optical science. Using MatLab and Mathematica, students will develop a toolkit for physical optics and build an intuition for wave propagation (e.g. transfer matrices), Fourier optics (beam propagation methods, normal mode analysis), light emission/absorption (surface- and cavity-enhanced lifetimes) as well as general finite difference schemes (frequency and time domain). Prerequisites: ENGN 0510 or PHYS 0470; APMA 0330 or APMA 0350; MATH 0520 or MATH 0540; or equivalent courses.

ENGN 2911K. Biological Impacts of Nanomaterials.
This course will emphasize advancements nanomaterials have made in several fields. In doing so, this course will cover fundamentals of nanomaterial synthesis and biological responses of nanomaterilas if ingested, inhaled, or implanted. Biological concepts (immune response, cellular toxicity, etc.) will be combined with engineering concepts (manufacturing and property control) to understand the relationship between manufacturing and biological impacts of nanomaterials.

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

ENGN 2911M. Instabilities and Turbulent Flows.
Introduction to hydrodynamic stability and the dynamics turbulent flows. Fundamentals of linear and nonlinear stability theory with a focus on shear flows, but also addressing examples of thin film and interfacial instabilities. Mechanics of turbulent flows including statistical descriptions, correlation functions, free-shear, and wall-bounded turbulence. Turbulence modeling and numerical methods.

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.

Spr	ENGN2911FS01	25824	W	3:00-5:30(10)	(L. Abriola)

ENGN 2911R. Analytical Modeling for Biomechanical and Biomedical Systems.
Students will develop a fundamental understanding of selected important statistical, physical and mathematical modeling methods for engineering and biomedical engineering applications. Topics covered will include analysis of variance, factorial design of experiments, modeling of infectious disease dynamics, soft material mechanics for cells and tissues and cancer tumor growth modeling. Students will learn introductory statistical methods, factorial design and analysis of experiments, introductory numerical methods, methods to model either time-dependent viscoelastic or nonlinear 3D large strain response of soft biological materials, and methods to develop mathematical models based on biological and physical knowledge. Students will learn applications of these methods for real-life problems and gain practice in critical analysis of scientific literature and effective oral and written technical communication. Prerequisite: APMA 0350 or a similar math background or instructor permission.

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.

ENGN 2911U. Hardware Architecture for Deep Learning.
Introduction to the design and implementation of hardware architectures for efficient processing of deep learning algorithms and tensor algebra in AI systems. Topics include basics of deep learning, optimization principles for programmable platforms such as GPUs, design principles of custom accelerator architectures, co-optimization of algorithms and hardware, including sparsity, and architectural implications of precision reduction. Includes labs involving modeling and analysis of hardware architectures, architecting deep learning inference systems, and an open-ended final design project. Class adapted (with permission) from MIT class 6.5930 by Professors Joel Emer and Vivian Sze, including lectures and labs. For Seniors and Graduate level students.

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.
In this course, we will study computing platforms featured with CPUs + FPGAs (field-programmable gate arrays) for reconfigurable customized computing. We will first cover architecture and programming models for FPGAs as an accelerator platform using high-level synthesis (HLS). Various customization techniques on FPGAs, including customized control flow and data flow, accelerator memory management, performance & energy modeling and optimization, and communication & computation optimization, will be discussed. We will then cover various application domains that use FPGAs as accelerators, including deep learning, computer vision, natural language processing, security-related applications, etc. This course welcomes enrollment from both undergraduate (seniors) and graduate students (all).

Fall	ENGN2911XS01	17095	W	3:00-5:30(10)	(P. Zhou)

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.

Fall	ENGN2912ES01	10304	MW	5:30-6:50	(D. Moreno)

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-of-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.

Fall	ENGN2912ES01	18089	MWF	10:00-10:50(14)	(M. Saligane)

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.

Fall	ENGN2912JS01	17319	MWF	12:00-12:50(15)	(T. Powers)

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

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

Fall	ENGN2912LS01	18087	MWF	12:00-12:50(15)	(J. Rosenstein)

ENGN 2912M. Introduction to Quantum Computing and Physical Basics of Computing.
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.
Theory and practice of experimental techniques for fluid mechanics. Principles of measurement, noise and error analysis, transduction and recording of signals. Measurement of temperature and pressure. Fundamentals of optics and image processing for measurements, Particle Image Velocimetry and Particle Tracking Velocimetry. Microfluidic and wind tunnel experimental techniques. Will include lab projects.

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.

Fall	ENGN2912L S01	10305	TTh	9:00-10:20(05)	(N. Ayanian)

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 homogenous 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).

ENGN 2920B. Mechanics of Energy Storage Materials.
This course introduces the students to the mechanics aspects of battery materials and some of the current research problems. It will consist of a series of lectures by experts from academia and industry, which will cover the state of the art in lithium ion batteries, the role of mechanics in advancing the field, experimental studies, continuum modeling, ab initio modeling and practical design issues. There will be approximately one lecture each week (150 min); each lecture will focus on a specific aspect of battery materials, giving an in-depth treatment of scientific problems, the current state of understanding and future challenges.

ENGN 2920D. Environmental Technologies and Human Health.
This course explores interdisciplinary approaches to environmental safety and health drawing from Brown University faculty and other affiliated experts. Topics include history of environmental regulation and waste management; origin and chemistry of pollutants; 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 (polycristals, wood, bone, blood), physical systems ((un)stable colloidal suspensions) or in engineering applications (fiber-reinforced materials, reinforced rubber in tires). They usually exhibit remarkable physical properties superior to the properties of individual components. Despite being comprised at the microscopic length scale of multiple domains with different physical properties, these materials behave as homogeneous materials and can be assigned macroscopic (effective) physical material-like properties for practical purposes. The course will cover classical and recent analytical, numerical methods for computation of various physical properties (viscous/thermal/dielectric, viscoelastic, thermoelastic, piezoelectric, electrostrictive) of heterogeneous materials that exhibit (non)linear and/or coupled behaviors.

ENGN 2920F. Sensors and Actuators for Real Systems.
This course was 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 and radar processing, 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.

Spr	ENGN2920H S01	20263	Arranged	'To Be Arranged'

ENGN 2930. Atomistic Modeling of Materials.
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.

Spr	ENGN2930	S01	20262	M	3:00-5:30(13)	(A. Van De Walle)

ENGN 2960. Experiential Learning in Industry (ELI).
This course will immerse students for up to 6 months in a corporate environment to learn first-hand about industry careers in engineering and technology. Corporate environments may include design, development, simulation, testing, technical documentation, consulting, investment, patent law, licensing, compliance, and/or regulations. Students will work as employees for a host company and carry out company-defined activities.

Fall	ENGN2960	S01	17007	Arranged		(C. Kofron)
Spr	ENGN2960	S01	25834	Arranged		(M. Gray)

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

Fall	ENGN2970	S01	16681	Arranged		'To Be Arranged'
Spr	ENGN2970	S01	25255	Arranged		'To Be Arranged'

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

ENGN 2990. Thesis Preparation.
For graduate students who have met the residency requirement and are continuing research on a full time basis.

Fall	ENGN2990	S01	16682	Arranged		'To Be Arranged'
Spr	ENGN2990	S01	25256	Arranged		'To Be Arranged'

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.