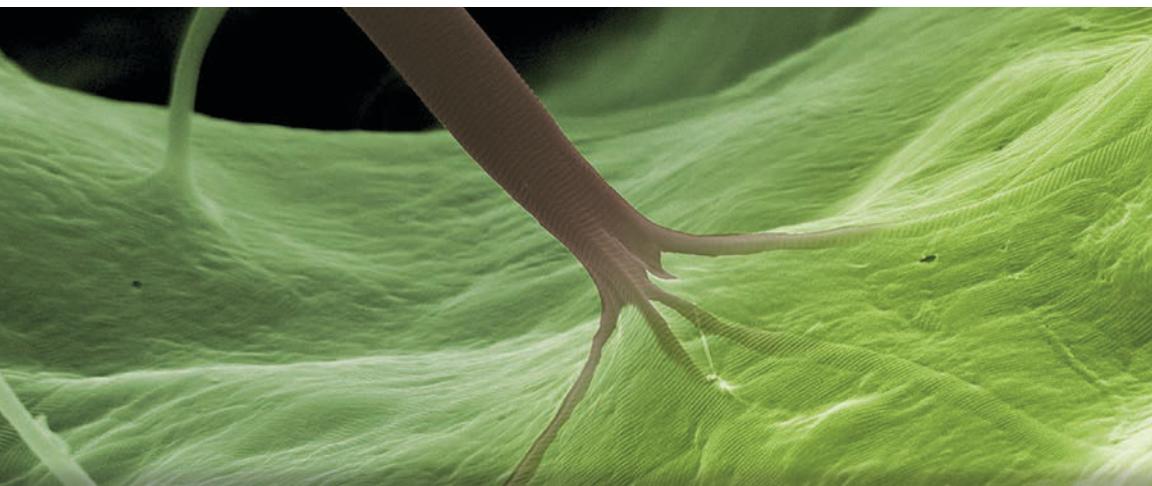


2018
2019

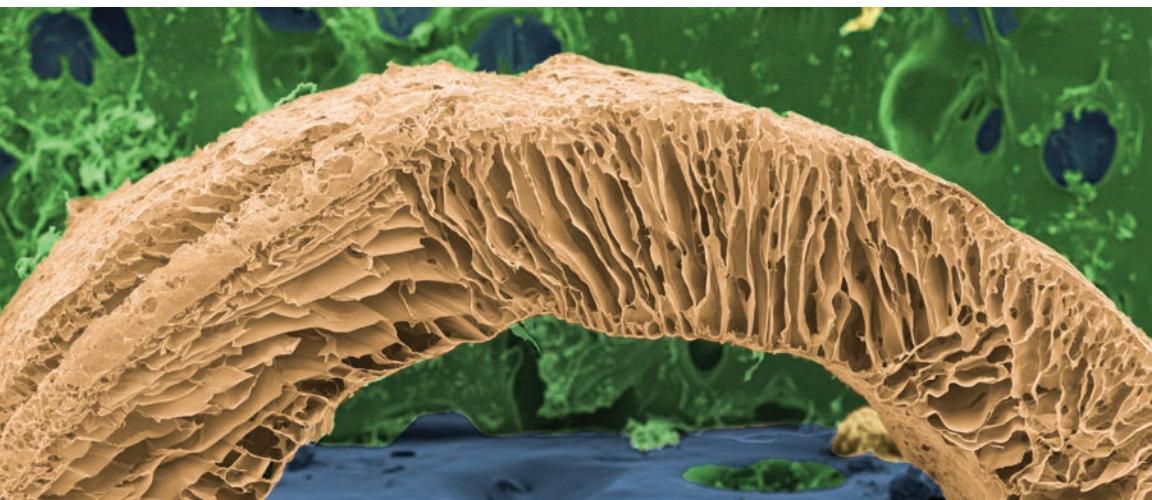


Guide to
Programs
and
Courses

Thayer School of Engineering
AT DARTMOUTH

engineering.dartmouth.edu

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Above: Inspired by the garden of Claude Monet, the "Japanese bridge" was a section of freeze-cast scaffolds, the "pond" and surrounding "plants" were created by conducting tape and collagen fibers. The image was taken by scanning electron microscope and modified in Photoshop by PhD candidate Kaiyang Yin, working in Professor Ulrike Wegst's lab.

Front and Back Cover: Freeze-cast collagen with self-assembled banding, imaged by scanning electron microscope by PhD candidate Kaiyang Yin, working in Professor Ulrike Wegst's lab.



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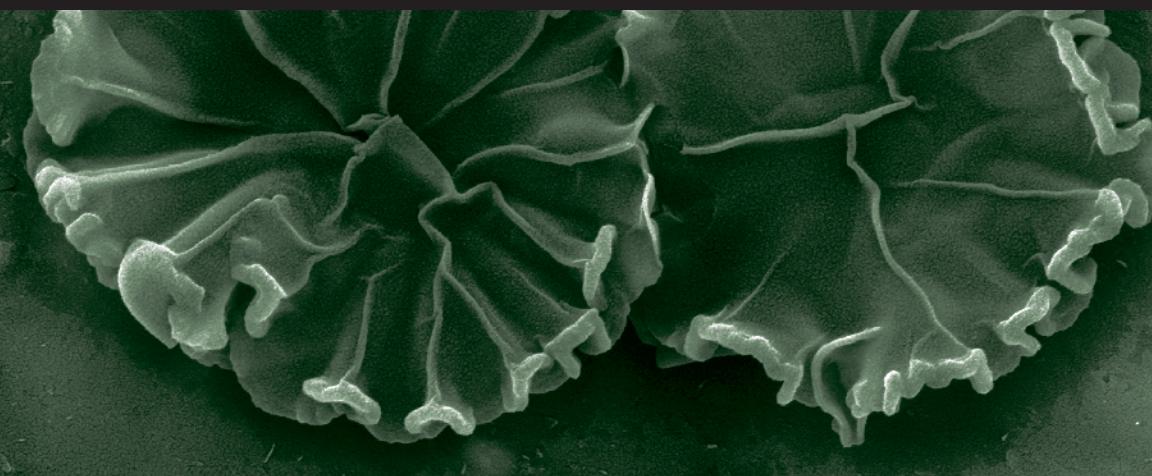
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Academic Calendar 2018-2019

engineering.dartmouth.edu/academics/calendar

| FALL TERM 2018 | |
|-------------------------------------|--|
| September 6 & 7, Thursday & Friday | Orientation for new students |
| September 11, Tuesday | Fall term check-in |
| September 12, Wednesday | Fall term classes begin |
| September 21, Friday | Final day for delayed check-in |
| September 22, Saturday | Special day of classes: courses meeting 10A period, 10:00; 2A period, 12:00; 3A/3B periods, 2:00 |
| October 20, Saturday | Special day of classes: courses meeting 10 period, 8:00; 11 period, 9:15; 12 period, 10:30; 2 period, 11:45 |
| October 26 & 27, Friday & Saturday | Homecoming |
| November 13, Tuesday | Fall classes end at 5:20 p.m.; pre-examination break begins |
| November 16–20, Friday–Tuesday | Fall term examinations |
| WINTER TERM 2019 | |
| January 2, Wednesday | Winter term check-in |
| January 3, Thursday | Winter term classes begin |
| January 12, Saturday | Final day for delayed check-in |
| January 21, Monday | Observance of Martin Luther King, Jr. Day (Classes moved to x-periods except 3A classes, which move to the 3B period on Tues., Jan. 22) |
| March 6, Wednesday | Winter term classes end at 5:20 p.m.; pre-examination break begins |
| March 9–12, Saturday–Tuesday | Winter term examinations |
| SPRING TERM 2019 | |
| March 24, Sunday | Spring term check-in |
| March 25, Monday | Spring term classes begin |
| April 3, Wednesday | Final day for delayed check-in |
| May 27, Monday | Memorial Day (College Holiday), no classes; first day of pre-examination break |
| May 29, Wednesday | Spring term classes end at 5:50 p.m. |
| May 30, Thursday | Second day of pre-examination break |
| May 31–June 3, Friday–Monday | Spring term examinations |
| June 8, Saturday | Thayer School Investiture Ceremony |
| June 9, Sunday | Dartmouth Commencement Day |
| SUMMER TERM 2019 (TENTATIVE) | |
| June 19, Wednesday | Summer term check-in |
| June 20, Thursday | Summer term classes begin |
| June 22, Saturday | Special day of classes: courses meeting 10A period, 10:00; 2A period, 12:00; 3A/3B periods, 2:00. Courses regularly held in other time sequences do not meet. |
| July 1, Monday | Final day for delayed check-in |
| July 4, Thursday | Independence Day (College Holiday), no classes |
| August 21, Wednesday | Summer term classes end at 5:20 p.m.; pre-examination break begins |
| August 24–27, Saturday–Tuesday | Summer term examinations |

Faculty



Micrometer-scale silica materials with a lotus-leaf-like structure, fabricated by using hexadecylamine as a structure-directing agent, high molecular weight polyvinylpyrrolidone as a structure-stabilizing agent, and tetraethyl orthosilicate as a silica precursor in the mixed solvents of water and ethanol. Imaged by transmission electron microscope by research associate Nanjing Hao, a member of Professor John Zhang's lab.

Faculty

engineering.dartmouth.edu/people/faculty

EMERITI

Alvin Omar Converse, PhD

Professor of Engineering, Emeritus

Robert C. Dean, Jr., ScD

Adjunct Professor of Engineering, Emeritus

Elsa Garmire, PhD

Sydney E. Junkins 1887 Professor, Emerita

Robert J. Graves, PhD

John H. Krehbiel Sr. Professor for Emerging Technologies, Emeritus

Charles Edgar Hutchinson, PhD

Dean of Thayer School, Emeritus

John H. Krehbiel Sr. Professor for Emerging Technologies, Emeritus

Francis E. Kennedy Jr., PhD

Professor of Engineering, Emeritus

William Lotko, PhD

Sue and John Ballard '55 TT'56 Professor, Emeritus

Daniel R. Lynch, PhD

MacLean Professor, Emeritus

Horst J. Richter, Dr-Ing

Professor of Engineering, Emeritus

Bengt Ulf Östen Sonnerup, PhD

Sydney E. Junkins 1887 Professor, Emeritus

Victor F. Petrenko, DSc

Research Professor, Emeritus

Graham B. Wallis, PhD

Sherman Fairchild Professor, Emeritus

ENDOWED PROFESSORSHIPS

George Austin Colligan Distinguished Professorship
Erland M. Schulson

Sherman Fairchild Professorship
Ian Baker

Dorothy and Walter Gramm Professorship
George Cybenko

Barry L. MacLean Professorship
Brian W. Pogue

Robert A. Pritzker Chair in Biomedical Engineering
Keith Paulsen

**Paul E. and Joan H. Queneau Distinguished Professorship
in Environmental Engineering Design**
Lee R. Lynd

Myron Tribus Professorship in Innovation
John P. Collier

CORE FACULTY

Margie Ackerman PhD

Associate Professor

Mary R. Albert PhD

Professor

Ian Baker DPhil

Sherman Fairchild Professor

Senior Associate Dean for Academic Affairs

Petra Bonfert-Taylor PhD

Professor

Zi Chen PhD

Assistant Professor

John P. Collier DE

Myron Tribus Professor in Innovation

Benoit Cushman-Roisin PhD

Professor

George Cybenko PhD

Dorothy and Walter Gramm Professor

Scott C. Davis PhD

Assistant Professor

Solomon G. Diamond PhD

Associate Professor

Jonathan Elliot PhD

Assistant Professor

Brenden P. Epps PhD

Assistant Professor

Jeremy Faludi PhD, LEED AP BD+C

Assistant Professor

Amro Farid PhD

Associate Professor

Eric Fossum PhD

John H. Krehbiel Sr. Professor for Emerging Technologies

Director, PhD Innovation Program

Associate Provost, Office of Entrepreneurship and Technology Transfer

Harold J. Frost PhD
Associate Professor

Tillman U. Gerngross PhD
Professor

Karl Griswold PhD
Associate Professor

Ryan J. Halter PhD
Assistant Professor

Eric W. Hansen PhD
Associate Professor

Alexander Hartov PhD
Professor

Joseph J. Helble PhD
Dean and Professor

Jane E. Hill PhD
Associate Professor

Shudong Jiang PhD
Associate Professor

Ronald C. Lasky PhD
Professor
Director, Cook Engineering Design Center

Christopher G. Levey PhD
Associate Professor
Director, Microengineering Laboratory
Director, Instructional Laboratories
Adjunct Professor of Physics and Astronomy

Weiyang (Fiona) Li PhD
Assistant Professor

Jifeng Liu PhD
Associate Professor

Geoffrey P. Luke PhD
Assistant Professor

Lee R. Lynd DE
Paul E. and Joan H. Queneau Distinguished Professor in Environmental
Engineering Design
Adjunct Professor of Biological Sciences

faculty

Matthew D.J. McGarry PhD

Assistant Professor

Vicki May PhD

Professor

Paul M. Meaney PhD

Professor

Kofi Odame PhD

Associate Professor

Daniel G. Olson PhD

Assistant Professor

Geoffrey P. Parker PhD

Professor

Director, MEM Programs

Keith D. Paulsen PhD

Robert A. Pritzker Chair in Biomedical Engineering

Professor of Radiology, Geisel School of Medicine

Scientific Director, Advanced Imaging Center, Dartmouth-Hitchcock Medical Center

Co-Director, Cancer Imaging and Radiobiology Research Program, Norris Cotton

Cancer Center

Donald K. Perovich PhD

Professor

Minh Q. Phan PhD

Associate Professor

Brian W. Pogue PhD

MacLean Professor of Engineering

Director, MS and PhD Programs

Professor of Physics and Astronomy

Professor of Surgery, Geisel School of Medicine

Laura R. Ray PhD

Professor

Peter J. Robbie MFA

Associate Professor

Eugene Santos Jr. PhD

Professor

Rahul Sarpeshkar PhD

Thomas E. Kurtz Professor

Professor

Professor of Physics

Professor of Microbiology and Immunology, Geisel School of Medicine

Professor of Molecular and Systems Biology, Geisel School of Medicine

Chair, Neukom Cluster of Computational Science

Erland M. Schulson PhD

George Austin Colligan Distinguished Professor
Chair, Engineering Sciences Department
Director, BE Program
Director, Ice Research Laboratory

Simon G. Shepherd PhD

Associate Professor

Fridon Shubitidze PhD

Associate Professor

Jason Stauth PhD

Associate Professor

Charles R. Sullivan PhD

Professor

Stephen Taylor PhD

Professor

B. Stuart Trembly PhD

Associate Professor

Douglas W. Van Citters PhD

Associate Professor

Vikrant Vaze PhD

Assistant Professor

Ulrike G.K. Wegst PhD

Associate Professor

John X.J. Zhang PhD

Professor

ADJUNCT AND VISITING FACULTY

Steven Arcone PhD

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Adjunct Assistant Professor

Benjamin Barrowes PhD

Research Physicist, U.S. Army Cold Regions Research and Engineering Laboratory
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Mark Borsuk PhD

Adjunct Associate Professor of Engineering

Jay C. Buckey Jr. MD

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Adjunct Professor of Engineering

Chi-Yang Cheng PhD

Professor of Medicine, Geisel School of Medicine
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David M. Cole PhD

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Zoe Courville PhD

Research Mechanical Engineer, U.S. Army Cold Regions Research and
Engineering Laboratory
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Adjunct Professor of Engineering

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Oliver Goodenough JD

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Adjunct Professor of Engineering

Richard H. Granger Jr. PhD

Professor of Psychological and Brain Sciences
Director, The Brain Engineering Laboratory
Adjunct Professor of Engineering

Richard M. Greenwald PhD

Co-Founder and President, Simbex, Lebanon, N.H.
Co-Founder, iWalk, Cambridge, Mass.
Adjunct Professor of Engineering

P. Jack Hoopes PhD

Associate Professor of Surgery and Radiation Oncology, Geisel School of Medicine
Director, Surgery and Radiation Research Laboratories
Co-Director, NCCC Cancer Nanotechnology Working Group
Adjunct Professor of Engineering

Michael Jermyn PhD

Adjunct Assistant Professor of Engineering

Songbai Ji DSc

Adjunct Associate Professor of Engineering

Stephen C. Kanick PhD

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Kevin O'Neill PhD

Research Civil Engineer, U.S. Army Cold Regions Research and Engineering Laboratory
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Ulf Osterberg PhD

Visiting Professor of Engineering

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Associate Professor of Surgery–Otolaryngology, Geisel School of Medicine
Chief, Section of Otolaryngology, Audiology, Maxillofacial Surgery,
Dartmouth-Hitchcock Medical Center
Adjunct Associate Professor of Engineering

Christopher Polashenski PhD

Research Geophysicist, U.S. Army Cold Regions Research and Engineering Laboratory
Adjunct Assistant Professor

Carl E. Renshaw PhD

Chair and Professor of Earth Sciences, Dartmouth College
Adjunct Professor of Engineering

David W. Roberts MD

Active Emeritus Professor of Surgery and Neurology, Geisel School of Medicine
Adjunct Professor of Engineering

Joseph M. Rosen MD

Professor of Surgery, Geisel School of Medicine
Adjunct Professor of Engineering

Kimberly Samkoe PhD

Department of Surgery, Dartmouth-Hitchcock Medical Center
Adjunct Assistant Professor

Scott A. Snyder PhD

Adjunct Assistant Professor

Harold M. Swartz PhD

Professor of Radiology and of Community and Family Medicine and of Physiology,
Geisel School of Medicine
Adjunct Professor of Engineering

Elijah Van Houten PhD

Senior Lecturer, University of Canterbury
Adjunct Associate Professor of Engineering

John B. Weaver PhD

Professor of Radiology, Geisel School of Medicine
Adjunct Professor

Benjamin B. Williams PhD

Associate Professor of Medicine, Geisel School of Medicine
Associate Professor of Radiology, Geisel School of Medicine
Adjunct Associate Professor of Engineering

LECTURERS

Daniel C. Cullen PhD

Project Lab, Materials Lab, Fluids Lab Manager

Kendall Hoyt PhD

Assistant Professor of Medicine, Geisel School of Medicine

Mark Laser PhD

Research Scientist

David Macaulay BArch

Eugene Korsunskiy MFA

Steven Peterson MS

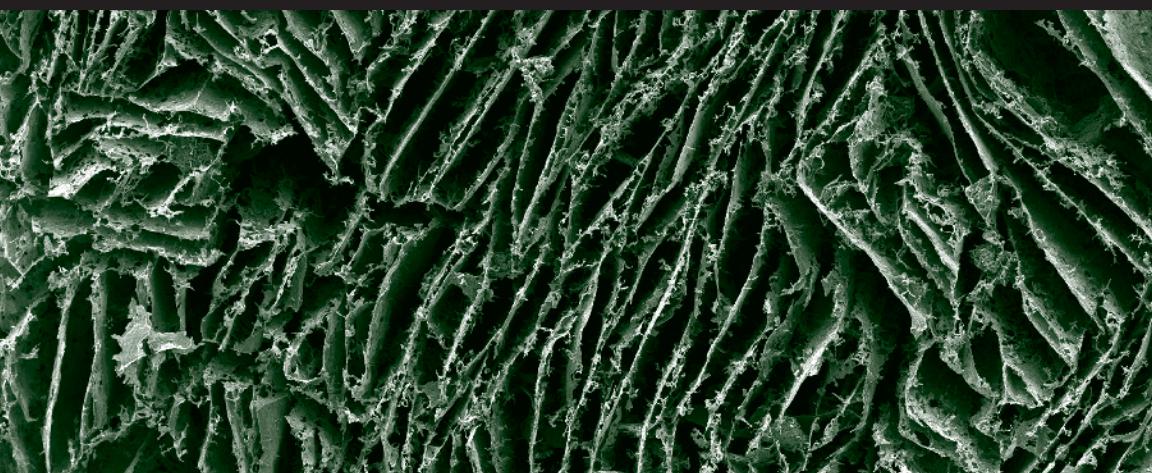
Independent Consultant

Markus Testorf PhD

John D. Wilson MArch

Senior Lecturer, Studio Art

Undergraduate Studies



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Cross section of reduced graphene oxide aerogel fabricated via freeze casting.
Imaged by scanning electron microscope by PhD candidate Danielle Castley,
working in Professor Ulrike Wegst's lab.

Undergraduate Studies

engineering.dartmouth.edu/academics/undergraduate

The goal of all engineering sciences programs is to educate students to apply technological skills to help meet societal needs, using concepts from a range of engineering disciplines.

ENGINEERING DEGREE PROGRAMS

Bachelor of Arts (AB) The engineering sciences major requires 7 prerequisites in mathematics and science, 9-10 courses in engineering sciences, and all College liberal arts requirements.

Bachelor of Engineering (BE) The BE degree, a professional degree recognized by the Engineering Accreditation Commission of ABET (abet.org), requires 9-10 engineering sciences courses beyond the AB degree.

AB/BE Program for Dartmouth Computer Science Majors Dartmouth students interested in computer science and engineering can major in Computer Science modified with Engineering or in Computer Science with an Engineering Sciences minor, then continue to the BE program for an additional year of study after the AB Students should plan their programs in consultation with a professor in each department to ensure that all degree requirements are met.

engineering.dartmouth.edu/academics/undergraduate/be/samples/computer-science-majors

AB/BE Program for Dartmouth Physics Majors Dartmouth students interested in physics and engineering can major in Engineering Physics or major in Physics with an Engineering Sciences minor, then continue to the BE program for an additional year of study after the AB Students should plan their programs in consultation with a professor in each department to ensure that all degree requirements are met.

engineering.dartmouth.edu/academics/undergraduate/be/samples/physics-majors

Dual-Degree Program. Students from colleges and universities other than Dartmouth can combine a bachelor's degree from their home institution with a BE from Thayer School. Information about the dual-degree program is at:

engineering.dartmouth.edu/academics/undergraduate/dual

PREREQUISITES

All engineering sciences majors, minors, and modified majors take 7 courses in mathematics, physics, computer science, and chemistry. First-year students should take the placement test in mathematics during orientation week. Unless otherwise prohibited, prerequisites may be taken under the Non-Recording Option.

ENGINEERING SCIENCES CURRICULUM

Students interested in the engineering sciences major or modified major should work with a faculty advisor to plan their study program early. Those interested in the combined AB/BE program should use the BE Program Plan to plan their course of study for both degrees.

The engineering sciences curriculum immerses students in the work of applying engineering theory to practical problems.

- Common core courses emphasize an integrated approach to problem solving, project management, and systems analysis
- Distributive core courses address fundamental concepts of engineering
- Gateway courses introduce students to specific engineering disciplines

In all courses, students practice critical thinking and communications, skills that mark the highly valued professional engineer.

ADVANCE PLANNING FOR THE MEM DEGREE

A large number of AB students plan their course of study to include the BE degree and then the Master of Engineering Management (MEM) degree. The MEM program combines engineering and management courses taught by Thayer School and Tuck School faculty and includes an industry internship (see page 48).

Planning your course selection with your faculty advisor early in your AB studies can enable you to complete the AB, BE, and MEM programs in 6 years. **AB students planning to do the MEM degree should take two engineering sciences electives beyond what is required for the major.** Delaying your planning until after you have entered the BE program will likely lengthen the completion time for the combined 3 degrees beyond 6 years. Applying for admission to the MEM program while in the AB is also possible.

See page 51 for a typical course sequence for completing the AB, BE, and MEM degrees in 6 years.

GRADE STANDARDS

Students taking courses for either the AB or BE degree are assigned grades ranging from A (for excellent) to E (not acceptable for degree credit). A "plus" or "minus" appended to a grade indicates a level slightly greater or lesser than the norm for that category. Grade point values are A = 4; A- = 3.67; B+ = 3.33; etc. The following guidelines offer general criteria for evaluation and grading, with "plus" or "minus" designations indicating that in the opinion of the instructor, the student has performed at a level slightly higher or lower than the norm for the category.

- A: Excellent mastery of course material
- B: Good mastery of course material
- C: Acceptable mastery of course material
- D: Deficient in mastery of course material
- E: Serious deficiency in mastery of course material.

AB candidates must maintain an average of 2.0 in courses for the major. BE candidates must maintain a grade average of C+ or better. Students who fail to maintain a C+ average in any term are placed on probation.

BE candidates are required to meet standards, in addition to earning a minimum grade point average of 2.33:

- no more than three (3) courses with grades below C, where C- is below C, will be counted towards the BE degree
- this number of 3 will be computed from all courses taken to satisfy BE requirements, excluding the prerequisites to the major in engineering sciences.

HONORS PROGRAM

engineering.dartmouth.edu/academics/undergraduate/ab/honors

AB students who have an overall grade point average of 3.0 with a 3.33 grade point average in the major are eligible for the Honors Program in Engineering Sciences. Applications are accepted between the second week of the fall term in the junior year and the second week of the winter term in the senior year. The honors project, either an experimental or a theoretical investigation, generally begins in ENGS 87 Undergraduate Investigations; the project itself, part of ENGS 88 Honors Thesis, includes a written thesis and an oral presentation.

Students who complete the Honors Program with a B+ average or better and have a grade point average of 3.33 or higher in the major receive a degree with "Honors in Engineering Sciences." A degree with "High Honors in Engineering Sciences" is awarded to students who, in addition to the above, have taken two Engineering Sciences courses beyond those required for the major (excluding courses under ENGS 20 and ENGS 87), have attained a grade point average of 3.50 in all engineering sciences courses, and have completed outstanding independent work.

ACADEMIC HONOR

All students, upon matriculation, sign an agreement to abide by the honor principles established by Dartmouth College and Thayer School. For AB candidates, the full statement of academic honor is at:

dartmouth.edu/~uja/honor

For BE candidates, the full statement is in the Thayer School student handbook, which students receive during registration for their first term.

FOREIGN STUDY

Credits earned at several institutions can be transferred toward either the AB or BE degree. Information about foreign study is at:

engineering.dartmouth.edu/academics/undergraduate/ab/foreign-study

Bachelor of Arts (AB)

engineering.dartmouth.edu/academics/undergraduate/ab

All AB engineering sciences programs are part of the liberal arts degree awarded by Dartmouth College.

| | |
|--|-----------|
| Liberal arts courses including writing, first-year seminar, foreign languages, humanities, social science, world culture | 10-14 |
| Mathematics and science prerequisites including calculus and physics | 7 |
| Engineering sciences courses for the major or modified major | 6-10 |
| Free electives including additional liberal arts or engineering sciences courses | 4-8 |
| Total courses | 35 |

Details of AB requirements can be found in the ORC/Catalog on Dartmouth's office of the Registrar website:

dartmouth.edu/~reg

AB ENGINEERING SCIENCES PROGRAMS

| DEGREE PROGRAM | BASIC MAJOR REQUIREMENTS | TOTAL | SEE PAGE |
|---|--|-------|----------|
| Engineering Sciences major | 9-10 engineering sciences courses, including a culminating experience | 9-10 | 20 |
| Biomedical Engineering Sciences major | 5 engineering sciences courses | 11 | 21 |
| | 4 biology and chemistry courses | | |
| | 1 biochemistry or engineering sciences elective | | |
| | Culminating experience in either engineering sciences or biochemistry | | |
| Engineering Physics major | 5 engineering sciences courses | 10 | 22 |
| | 5 physics courses | | |
| | Culminating experience in EITHER engineering sciences OR physics | | |
| Engineering Sciences major modified by another discipline | 6-7 courses in engineering sciences including a culminating experience | 10-11 | 23-34 |
| | 4 courses in the other discipline | | |
| Engineering Sciences minor | 5 courses in math and physics plus 5 courses in engineering sciences | 10 | 35 |
| Human-Centered Design minor | 2 engineering sciences courses | 6 | 36 |
| | 4 courses in other discipline | | |
| Materials Science minor | 4 materials science courses | 10 | 37 |
| | 6 courses in chemistry, physics, OR engineering sciences | | |
| Major modified by Engineering Sciences | 3-4 courses in math and physics plus 4 courses in engineering sciences | 7-8 | 38 |

Culminating Experience

Engineering Sciences majors, modified majors, and Engineering Physics majors complete a culminating experience, which is part of a course (either as one of the two electives or as an additional course). Normally taken during the senior year, the course is chosen from the following:

| | |
|------------------------|---|
| Thesis | ENGS 86 Independent Project OR ENGS 88 Honors Thesis |
| Design project | ENGS 89* Engineering Design Methodology and Project Initiation (taken as part of the two-course design sequence ENGS 89/90). May count toward both AB and BE degrees. |
| Advanced course | An advanced engineering sciences course with a significant design or research project chosen from an approved list available from the chair of the Engineering Sciences Department or at engineering.dartmouth.edu/academics/undergraduate/ab/major Biomedical Engineering Sciences majors should choose from ENGS 160, 161, 162, 163, 165, 167 or 169. Engineering Physics majors may also choose from PHYS 68, 72, 73, 74, 76, 82, 87 |

* Prior to enrollment in ENGS 89, at least 6 engineering sciences courses must be completed: ENGS 21 plus 5 additional courses numbered 22 to 76 (excluding 75) and 91 and above.

ENGINEERING AS A FOUNDATION FOR PROFESSIONAL FIELDS

A major in engineering sciences serves as an entry into any field where problem solving, analytical thinking and inventiveness are important. For students interested in specific professional fields, the following majors, minors, and modified majors are possible:

| PROFESSIONAL FIELD | MAJOR | SEE PAGE |
|--|---|----------|
| Architecture | Engineering Sciences major modified with Studio Art | 34 |
| Biomedical engineering | Biomedical Engineering Sciences major | 21 |
| Biotechnology | Engineering Sciences major modified with Biology | 23 |
| Chemical engineering | Engineering Sciences major modified with Chemistry | 24 |
| Computer engineering | Engineering Sciences major modified with Computer Science | 25 |
| Environmental engineering | Engineering Sciences major modified with Environmental Sciences | 28 |
| Any engineering field or interdisciplinary engineering | Engineering Sciences major | 20 |
| Engineering physics | Engineering Physics major | 22 |
| Geology | Engineering Sciences major modified with Earth Sciences | 26 |
| Human-centered design | Human-Centered Design minor | 36 |
| Management and financial engineering | Engineering Sciences major modified with Economics | 27 |
| Materials science | Materials Science minor with Chemistry or Physics major | 37 |
| Medicine | Biomedical Engineering Sciences major | 21 |
| Neuroscience | Engineering Sciences major modified with Neuroscience | 30 |
| Product design | Engineering Sciences major modified with Studio Art | 34 |
| Technology in public policy | Engineering Sciences modified with Public Policy | 32 |

Students interested in professional fields other than those listed above can create modified majors tailored to their interests. A coherent program of study with substantial engineering content should be developed in consultation with the chair of the engineering department, Professor Erland Schulson, and filed with the registrar.

ENGINEERING SCIENCES MAJOR

| PREREQUISITES | | | | | | | | | | |
|---|---|------------------------------------|---|----------------------------|---|-----------------------------|---|----------------------|---|-----------|
| Mathematics | MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 11 Multivariable Calculus for Two-Term Advanced Placement First-Year Students OR MATH 13 Calculus of Vector-Valued Functions | 3 courses | | | | | | | | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses | | | | | | | | |
| Chemistry | CHEM 5 General Chemistry | 1 course | | | | | | | | |
| Computer Science (choose 1 option) | ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | 1-2 courses | | | | | | | | |
| REQUIRED COURSES | | | | | | | | | | |
| Common core courses | ENGS 21 Introduction to Engineering** ENGS 22 Systems ENGS 23 Distributed Systems and Fields | 3 courses | | | | | | | | |
| Distributive core courses (choose 2) | ENGS 24 Science of Materials ENGS 25 Introduction to Thermodynamics ENGS 26 Control Theory ENGS 27 Discrete and Probabilistic Systems | 2 courses | | | | | | | | |
| Gateway courses (choose 2, each from a different discipline) | <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%; vertical-align: top; padding-right: 10px;">Electrical</td><td>ENGS 31 Digital Electronics ENGS 32 Electronics: Introduction to Linear and Digital Circuits</td></tr> <tr> <td style="width: 20%; vertical-align: top; padding-right: 10px;">Mechanical</td><td>ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics</td></tr> <tr> <td style="width: 20%; vertical-align: top; padding-right: 10px;">Chemical/biochemical</td><td>ENGS 30 Biological Physics ENGS 35 Biotechnology and Biochemical Engineering ENGS 36 Chemical Engineering</td></tr> <tr> <td style="width: 20%; vertical-align: top; padding-right: 10px;">Environmental</td><td>ENGS 37 Introduction to Environmental Engineering</td></tr> </table> | Electrical | ENGS 31 Digital Electronics ENGS 32 Electronics: Introduction to Linear and Digital Circuits | Mechanical | ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics | Chemical/biochemical | ENGS 30 Biological Physics ENGS 35 Biotechnology and Biochemical Engineering ENGS 36 Chemical Engineering | Environmental | ENGS 37 Introduction to Environmental Engineering | 2 courses |
| Electrical | ENGS 31 Digital Electronics ENGS 32 Electronics: Introduction to Linear and Digital Circuits | | | | | | | | | |
| Mechanical | ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics | | | | | | | | | |
| Chemical/biochemical | ENGS 30 Biological Physics ENGS 35 Biotechnology and Biochemical Engineering ENGS 36 Chemical Engineering | | | | | | | | | |
| Environmental | ENGS 37 Introduction to Environmental Engineering | | | | | | | | | |
| Electives (choose 2, either both from the engineering sciences option or one from each option) | <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%; vertical-align: top; padding-right: 10px;">Engineering sciences option</td><td>Any engineering sciences (ENGS) course above ENGS 20 (excluding ENGS 87)</td></tr> <tr> <td style="width: 20%; vertical-align: top; padding-right: 10px;">Science/math option</td><td>ASTR 15 and above; BIOL 12 and above (except 52); CHEM 6, 10 and above (except 63); EARS 31, 33, 35, 37, 40-52, 59, 62, 64, 66-75, 79 and above; ENVS 30 and 79; MATH 17 – 29, 31, 32, 35, 38, 39, 40, 42, 43, 50 and above; PHYS 19 or 40 (formerly 24), 41 and above (except 48); COSC 30, 31, 39, 49, 71, 74</td></tr> </table> | Engineering sciences option | Any engineering sciences (ENGS) course above ENGS 20 (excluding ENGS 87) | Science/math option | ASTR 15 and above; BIOL 12 and above (except 52); CHEM 6, 10 and above (except 63); EARS 31, 33, 35, 37, 40-52, 59, 62, 64, 66-75, 79 and above; ENVS 30 and 79; MATH 17 – 29, 31, 32, 35, 38, 39, 40, 42, 43, 50 and above; PHYS 19 or 40 (formerly 24), 41 and above (except 48); COSC 30, 31, 39, 49, 71, 74 | 2 courses | | | | |
| Engineering sciences option | Any engineering sciences (ENGS) course above ENGS 20 (excluding ENGS 87) | | | | | | | | | |
| Science/math option | ASTR 15 and above; BIOL 12 and above (except 52); CHEM 6, 10 and above (except 63); EARS 31, 33, 35, 37, 40-52, 59, 62, 64, 66-75, 79 and above; ENVS 30 and 79; MATH 17 – 29, 31, 32, 35, 38, 39, 40, 42, 43, 50 and above; PHYS 19 or 40 (formerly 24), 41 and above (except 48); COSC 30, 31, 39, 49, 71, 74 | | | | | | | | | |
| Culminating experience | Thesis, design project, or advanced course (see page 18) | | | | | | | | | |

For advice, contact the chair of Engineering Sciences, Professor Erland Schulson.

* May not be taken under the Non-Recording Option (NRO).

** Should be taken sophomore year.

BIOMEDICAL ENGINEERING SCIENCES MAJOR

The biomedical engineering sciences major is offered to students interested in medical school. Faculty from Thayer School and Geisel School of Medicine jointly advise the research projects. Geisel School of Medicine offers an opportunity for accomplished biomedical engineering sciences majors to apply for early admission to the Geisel School of Medicine through the Early Assurance Program. For more information, please consult the Thayer website at:

engineering.dartmouth.edu/academics/undergraduate/ab/biomed-major

| PREREQUISITES | | |
|--|---|-------------|
| Mathematics | MATH 3 Introduction to Calculus MATH 8 Calculus of One and Several Variables MATH 13 Calculus of Vector-Valued Functions OR MATH 11 Multivariable Calculus for Two-Term Advanced Placement First-Year Students | 3 courses |
| Chemistry | CHEM 5–6 General Chemistry OR CHEM 10 Honors First-Year Chemistry | 1–2 courses |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Computer Science (choose 1 option) | ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | 1–2 courses |
| REQUIRED COURSES | | |
| Common core courses | ENGS 21 Introduction to Engineering*** ENGS 22 Systems | 2 courses |
| Common and distributive core courses (choose 1) | ENGS 23 Distributed Systems and Fields ENGS 24 Science of Materials ENGS 25 Introduction to Thermodynamics ENGS 26 Control Theory ENGS 27 Discrete and Probabilistic Systems | 1 course |
| Gateway course (choose 1) | Electrical ENGS 31 Digital Electronics ENGS 32 Electronics: Introduction to Linear and Digital Circuits Mechanical ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics Chemical/biochemical ENGS 30 Biological Physics ENGS 35 Biotechnology and Biochemical Engineering ENGS 36 Chemical Engineering | 1 course |
| Engineering course (choose 1) | ENGS 56 Biomedical Engineering OR 1 additional course from ENGS 23–26 | 1 course |
| Biology courses (choose 2) | BIOL 12 Cell Structure and Function BIOL 13 Gene Expression and Inheritance BIOL 30 Physiology | 2 courses |
| Chemistry courses | CHEM 51–52 Organic Chemistry OR CHEM 57–58 Organic Chemistry | 2 courses |
| Elective** (choose 1) | Engineering Sciences course numbered above ENGS 23 BIOL 40 Biochemistry CHEM 41 Biological Chemistry | 1 course |
| Culminating experience | Thesis or advanced course (see page 18) | 1 course |

For advice, contact Professor Brian Pogue, Solomon Diamond, or Douglas Van Citters.

* May not be taken under the Non-Recording Option (NRO).

** Students wishing to pursue the BE degree are advised to choose an Engineering Sciences course as their elective.

*** Should be taken sophomore year.

ENGINEERING PHYSICS MAJOR

The departments of Engineering Sciences and Physics and Astronomy offer the major in Engineering Physics.

| PREREQUISITES | | |
|---|--|--|
| Mathematics | MATH 3 Introduction to Calculus | 4 courses |
| | MATH 8 Calculus of Functions of One and Several Variables | |
| | MATH 13 Calculus of Vector-Valued Functions | |
| | MATH 23 Differential Equations | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Chemistry | CHEM 5 General Chemistry | 1 course |
| Computer Science (choose 1 option) | ENGS 20 Introduction to Scientific Computing* | 1-2 courses |
| | COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | |
| REQUIRED COURSES | | |
| Engineering core courses | ENGS 22 Systems | 3 courses |
| | ENGS 23 Distributed Systems and Fields | |
| | ENGS 24 Science of Materials | |
| Physics core courses** | PHYS 19 Introductory Physics III | 3 courses |
| | PHYS 40 Quantum Physics of Matter: An Introduction | |
| | PHYS 43 Statistical Physics | |
| Electives*** (choose 2, each from a different group) | Group 1 | ENGS 25 Introduction to Thermodynamics |
| | | ENGS 33 Solid Mechanics |
| | | ENGS 34 Fluid Dynamics |
| | Group 2 | PHYS 50 Introductory Quantum Mechanics |
| | | PHYS 68 Introductory Plasma Physics |
| | | PHYS 91 Intermediate Quantum Mechanics |
| | Group 3 | PHYS 73 Introductory Condensed Matter Physics |
| | | ENGS 131 Science of Solid State Materials |
| | | PHYS 66 Relativistic Electrodynamics |
| | Group 4 | ENGS 64 Engineering Electromagnetics or ENGS 120 Electromagnetic Waves**** |
| | | PHYS 44 Mechanics |
| | | ENGS 72 Applied Mechanics: Dynamics |
| Free electives*** (choose 2) | Any Engineering Sciences courses numbered above 20 (excluding ENGS 80 and 87) OR any physics course that fulfills the straight physics major | |
| Culminating experience | Thesis, design project, or advanced course (see page 18) | |

For advice, contact Professor Jifeng Liu.

* May not be taken under the Non-Recording Option (NRO).

** Students taking the honors sequence, PHYS 15 and 16, should substitute a third physics elective for PHYS 19.

*** The Engineering Physics Major must be a 5/5 split of 10 courses between Engineering Sciences and Physics. These courses include the required 3 core courses and 2 electives or free electives in engineering and 2 electives or free electives in physics. Students wishing to pursue the BE degree are advised to elect an Engineering Sciences course.

**** Either ENGS 64 or ENGS 120 may serve as an elective here but not both.

ENGINEERING SCIENCES MODIFIED WITH BIOLOGY

| PREREQUISITES | | |
|--|--|-----------|
| Mathematics | MATH 3 Introduction to Calculus | 3 courses |
| | MATH 8 Calculus of Functions of One and Several Variables | |
| | MATH 13 Calculus of Vector-Valued Functions | |
| Physics | PHYS 13, 14 Introduction to Physics I, II | 2 courses |
| Chemistry (choose 1) | CHEM 5 General Chemistry | 1 course |
| | CHEM 10 Honors First-Year General Chemistry | |
| Computer Science (choose 1 option) | ENGSS 20 Introduction to Scientific Computing* | 1 course |
| | COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | |
| Biology | BIOL 12 Cell Structure and Function | 1 course |
| REQUIRED COURSES | | |
| Engineering core courses | ENGSS 22 Systems | 3 courses |
| | ENGSS 25 Introduction to Thermodynamics | |
| | ENGSS 35 Biotechnology and Biochemical Engineering | |
| Engineering electives (choose 3) | ENGSS 21 Introduction to Engineering** | 3 courses |
| | ENGSS 23 Distributed Systems and Fields | |
| | ENGSS 24 Science of Materials | |
| | ENGSS 26 Control Theory | |
| | ENGSS 33 Solid Mechanics | |
| | ENGSS 34 Fluid Dynamics | |
| | ENGSS 36 Chemical Engineering | |
| | ENGSS 37 Introduction to Environmental Engineering | |
| | ENGSS 52 Introduction to Operations Research | |
| | ENGSS 56 Introduction to Biomedical Engineering | |
| | ENGSS 58 Introduction to Protein Engineering | |
| | ENGSS 91 Numerical Methods in Computation | |
| Biology core course | ENGSS 161 Metabolic Engineering | 1 course |
| | ENGSS 162 Methods in Biotechnology | |
| | ENGSS 165 Biomaterials | |
| Biology or chemistry electives (choose 3) | BIOL 13 Gene Expression and Inheritance | 3 courses |
| | BIOL 37 Endocrinology | |
| | BIOL 42 Biology of the Immune Response | |
| | BIOL 43 Developmental Biology | |
| | BIOL 45 Molecular Biology | |
| | BIOL 46 Microbiology | |
| Culminating experience | BIOL 71 Current Topics in Cell Biology | |
| | CHEM 51 Organic Chemistry OR CHEM 57 Honors Organic Chemistry | |
| | Thesis, design project, or advanced course (see page 18) | |

For advice, contact Professor Lee Lynd.

* May not be taken under the Non-Recording Option (NRO).

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH CHEMISTRY

| PREREQUISITES | | |
|--|--|-------------|
| Mathematics | MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions | 3 courses |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Chemistry | CHEM 5-6 General Chemistry OR CHEM 10 Honors First-Year General Chemistry | 1-2 courses |
| Computer Science (choose 1 option) | ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | 1 course |
| REQUIRED COURSES | | |
| Engineering core courses | ENGS 22 Systems ENGS 25 Introduction to Thermodynamics ENGS 36 Chemical Engineering | 3 courses |
| Engineering electives (choose 3 with not more than 2 from 21, 35, and 37 counting toward the major) | ENGS 21 Introduction to Engineering ENGS 23 Distributed Systems and Fields ENGS 24 Science of Materials ENGS 26 Control Theory ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics ENGS 35 Biotechnology and Biochemical Engineering ENGS 37 Introduction to Environmental Engineering ENGS 52 Introduction to Operations Research ENGS 91 Numerical Methods in Computation ENGS 156 Heat, Mass, and Momentum Transfer ENGS 158 Chemical Kinetics and Reactors | 3 courses |
| Chemistry core courses | CHEM 51 Organic Chemistry OR CHEM 57 Honors Organic Chemistry CHEM 75 Physical Chemistry I | 2 courses |
| Chemistry electives (choose 2) | CHEM 41 Biological Chemistry I CHEM 52 Organic Chemistry OR 58 Honors Organic Chemistry CHEM 63 Environmental Chemistry CHEM 64 Basic Inorganic Chemistry CHEM 67 Physical Biochemistry I CHEM 76 Physical Chemistry II | 2 courses |
| Culminating experience | Thesis, design project, or advanced course (see page 18) | |

For advice, contact Professor Lee Lynd.

* May not be taken under the Non-Recording Option (NRO).

ENGINEERING SCIENCES MAJOR MODIFIED WITH COMPUTER SCIENCE

| PREREQUISITES | | | |
|---|---|-----------|--|
| Mathematics | MATH 3 Introduction to Calculus | 3 courses | |
| | MATH 8 Calculus of Functions of One and Several Variables | | |
| | MATH 13 Calculus of Vector-Valued Functions | | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses | |
| Chemistry | CHEM 5 General Chemistry | 1 course | |
| Computer Science | COSC 1 Introduction to Programming and Computation | 2 courses | |
| | COSC 10 Problem Solving via Object-Oriented Programming | | |
| REQUIRED COURSES | | | |
| Engineering core courses (all of Group 1; choose 1 from Group 2) | Group 1 | 4 courses | |
| | | | |
| | | | |
| Computer Science course | Group 2 | 1 course | |
| | | | |
| | | | |
| Breadth requirements (choose 5 including at least 1 from each group and 3 in Computer Science) | Group 1 | 5 courses | |
| | | | |
| | | | |
| | Group 2 | | |
| | | | |
| | | | |
| | Group 3 | | |
| | | | |
| | | | |
| Culminating experience | Thesis, design project, or advanced course (see page 18) | | |

For advice, contact Professor Eugene Santos or Professor Steve Taylor.

ENGINEERING SCIENCES MAJOR MODIFIED WITH EARTH SCIENCES

| PREREQUISITES | | |
|---|---|-----------|
| Mathematics | MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions | 3 courses |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Chemistry | CHEM 5 General Chemistry | 1 course |
| Computer Science (choose 1 option) | ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | 1 course |
| Earth Sciences | 1 introductory Earth Sciences course from EARS 1-9, exclusive of EARS 7 EARS 40 Materials of the Earth | 2 courses |
| REQUIRED COURSES | | |
| Engineering Sciences | ENGS 22 Systems ENGS 23 Distributed Systems and Fields ENGS 24 Science of Materials ENGS 25 Introduction to Thermodynamics 2 Engineering Sciences electives | 6 courses |
| Earth Sciences | 4 Earth Sciences courses numbered above 10 | 4 courses |
| Culminating Experience | Thesis, design project, or advanced course (see page 18) | |

For advice, contact Professor Erland Schulson.

* May not be taken under the Non-Recording Option (NRO).

ENGINEERING SCIENCES MAJOR MODIFIED WITH ECONOMICS

| PREREQUISITES | | | |
|---|---|-------------|--|
| Mathematics | MATH 3 Introduction to Calculus | 3 courses | |
| | MATH 8 Calculus of Functions of One and Several Variables | | |
| | MATH 13 Calculus of Vector-Valued Functions | | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses | |
| Chemistry | CHEM 5 General Chemistry | 1 course | |
| Computer Science (choose 1 option) | ENG 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | 1-2 courses | |
| Economics | ECON 1 The Price System: Analysis, Problems, and Policies | 2 courses | |
| | ECON 10 Introduction to Statistical Methods | | |
| REQUIRED COURSES | | | |
| Engineering core courses | ENG 21 Introduction to Engineering** | 3 courses | |
| | ENG 22 Systems | | |
| | ENG 52 Introduction to Operations Research | | |
| Engineering electives (choose 1 from Group 1; 2 from Group 2) | Group 1 ENG 23 Distributed Systems and Fields ENG 24 Science of Materials ENG 25 Introduction to Thermodynamics ENG 33 Solid Mechanics | 3 courses | |
| | | | |
| | | | |
| | Group 2 Any other Engineering Sciences course that counts toward the AB | | |
| Economics courses (choose 2) | ECON 20 Econometrics | 2 courses | |
| | ECON 21 Microeconomics | | |
| | ECON 22 Macroeconomics | | |
| Economics electives (choose a 2-course sequence from a single group) | Money and Finance ECON 26 The Economics of Financial Intermediaries and Markets ECON 36 Theory of Finance | 2 courses | |
| | | | |
| | Industrial Organization ECON 25 Industrial Organization and Public Policy ECON 35 Games and Economic Behavior OR ECON 45 Topics in Industrial Organization | | |
| | | | |
| | International Trade ECON 29 International Finance and Open-Economy Macroeconomics ECON 39 International Trade | | |
| | | | |
| Culminating experience | Thesis, design project, or advanced course (see page 18) | | |

For advice, contact Professor Geoffrey Parker.

* May not be taken under the Non-Recording Option (NRO).

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH ENVIRONMENTAL SCIENCES

| PREREQUISITES | | |
|---|--|-----------|
| Mathematics | MATH 3 Introduction to Calculus | 3 courses |
| | MATH 8 Calculus of Functions of One and Several Variables | |
| | MATH 13 Calculus of Vector-Valued Functions | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Chemistry (choose 1) | CHEM 5 General Chemistry | 1 course |
| | CHEM 10 Honors First-Year General Chemistry | |
| Computer Science (choose 1 option) | ENG 20 Introduction to Scientific Computing* | 1 course |
| | COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | |
| Biology | BIOL 16 Ecology | 1 course |
| REQUIRED COURSES | | |
| Engineering core courses | ENG 22 Systems | 3 courses |
| | ENG 25 Introduction to Thermodynamics | |
| | ENG 37 Introduction to Environmental Engineering | |
| Engineering electives (choose 3, of which at least 2 must be from the sub-group 41, 43, 44, 171) | ENG 27 Discrete and Probabilistic Systems | 3 courses |
| | ENG 34 Fluid Dynamics | |
| | ENG 35 Biotechnology and Biochemical Engineering | |
| | ENG 36 Chemical Engineering | |
| | ENG 41 Sustainability and Natural Resource Management | |
| | ENG 43 Environmental Transport and Fate | |
| | ENG 44 Sustainable Design | |
| | ENG 52 Introduction to Operations Research | |
| | ENG 171 Industrial Ecology | |

continued

ENGINEERING SCIENCES MAJOR MODIFIED WITH ENVIRONMENTAL SCIENCES cont.

| REQUIRED COURSES | |
|--|---|
| Environmental Sciences courses (choose 4, including at least 2 from a single department) | Biology BIOL 21 Population Ecology OR BIOL 51 Advanced Population Ecology BIOL 22 Methods in Ecology BIOL 25 Introductory Marine Biology and Ecology BIOL 27 Animal Behavior OR BIOL 68 Advanced Animal Behavior (but not both) BIOL 53 Aquatic Ecology |
| | Chemistry CHEM 51 Organic Chemistry (only as prerequisite to CHEM 63) CHEM 63 Environmental Chemistry |
| | Earth Sciences EARS 16 Hydrology and Water Resources EARS 35 The Soil Resource EARS 65 Remote Sensing EARS 71 River Processes and Watershed Science EARS 66 Hydrogeology EARS 76 Advanced Hydrology |
| | Environmental Studies ENVS 12 Energy and the Environment ENVS 15 Environmental issues of Earth's Cold Regions ENVS 20 Conservation of Biodiversity ENVS 25 Ecological Agriculture ENVS 30 Global Environmental Science ENVS 53 Science for Sustainable Systems |
| | Culminating experience Thesis, design project, or advanced course (see page 18) |
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For advice, contact Professor Benoit Cushman-Roisin or Professor Lee Lynd.

* May not be taken under the Non-Recording Option (NRO).

ENGINEERING SCIENCES MODIFIED WITH NEUROSCIENCE

| PREREQUISITES | | |
|---|--|-------------|
| Mathematics | MATH 3 Introduction to Calculus | 3 courses |
| | MATH 8 Calculus of Functions of One and Several Variables | |
| | MATH 13 Calculus of Vector-Valued Functions | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Chemistry | CHEM 5 General Chemistry | 1 course |
| Computer Science (choose 1 option) | ENGS 20 Introduction to Scientific Computing* | 1-2 courses |
| | COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | |
| Neuroscience | PSYC 6 Introduction to Neurosciences | 1 course |
| REQUIRED COURSES | | |
| Engineering core courses | ENGS 21 Introduction to Engineering** | 4 courses |
| | ENGS 22 Systems | |
| | ENGS 26 Control Theory OR ENGS 27 Discrete and Probabilistic Systems | |
| | ENGS 31 Digital Electronics OR ENGS 32 Electronics: Introduction to Linear and Digital Circuits | |
| | ENGS 26 Control Theory (if not taken above) | |
| Engineering electives (choose 2) | ENGS 27 Discrete and Probabilistic Systems (if not taken above) | 2 courses |
| | ENGS 30 Biological Physics | |
| | ENGS 31 Digital Electronics (if not taken above) | |
| | ENGS 32 Electronics: Introduction to Linear and Digital Circuits (if not taken above) | |
| | ENGS 33 Solid Mechanics | |
| | ENGS 56 Introduction to Biomedical Engineering | |
| | ENGS 57 Intermediate Biomedical Engineering | |
| | ENGS 61 Intermediate Electrical Circuits | |
| | ENGS 62 Microprocessors in Engineered Systems | |
| | ENGS 65 Engineering Software Design | |
| | ENGS 67 Programming Parallel Systems | |
| | ENGS 93 Statistical Methods in Engineering | |

continued

ENGINEERING SCIENCES MODIFIED WITH NEUROSCIENCE cont.

| REQUIRED COURSES | |
|---|---|
| Neuroscience core courses (choose 2) | PSYC 45 Behavioral Neuroscience PSYC 46 Cellular and Molecular Neuroscience PSYC 65 Systems Neuroscience (formerly Physiology of Behavior) |
| | 2 courses |
| Neuroscience electives (choose 2) | PSYC 21 Perception PSYC 27 Cognitive Neuroscience PSYC 40 Introduction to Computational Neuroscience PSYC 60 Principles of Human Brain Mapping with fMRI BIOL 27 Animal Behavior PSYC 80–87 Seminars in Neuroscience (allow one seminar only as one of the two electives) |
| | 2 courses |
| Culminating experience | Thesis, design project, or advanced course (see page 18) |

For advice, contact Professor Laura Ray.

* May not be taken under the Non-Recording Option (NRO).

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH PUBLIC POLICY

| PREREQUISITES | | |
|---|--|--|
| Mathematics | MATH 3 Introduction to Calculus | 3 courses |
| | MATH 8 Calculus of Functions of One and Several Variables | |
| | MATH 13 Calculus of Vector-Valued Functions | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Chemistry | CHEM 5 General Chemistry | 1 course |
| Computer Science (choose 1 option) | ENGS 20 Introduction to Scientific Computing* | 1-2 courses |
| | COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | |
| Statistical data analysis (choose 1) | ECON 10 Introduction to Statistical Methods | 1 course |
| | GOVT 10 Quantitative Political Analysis | |
| | SOCY 10 Quantitative Analysis of Social Data | |
| | MATH 10 Introductory Statistics | |
| REQUIRED COURSES | | |
| Engineering core courses | ENGS 21 Introduction to Engineering** | 2 courses |
| | ENGS 22 Systems | |
| Engineering electives (choose 1 from each group) | Group 1 | ENGS 23 Distributed Systems and Fields |
| | | ENGS 24 Science of Materials |
| | | ENGS 25 Introduction to Thermodynamics |
| | | ENGS 26 Control Theory |
| | | ENGS 27 Discrete and Probabilistic Systems |
| | Group 2 | ENGS 30 Biological Physics |
| | | ENGS 31 Digital Electronics |
| | | ENGS 32 Electronics: Introduction to Linear and Digital Circuits |
| | | ENGS 33 Solid Mechanics |
| | | ENGS 34 Fluid Dynamics |
| | | ENGS 35 Biotechnology and Biochemical Engineering |
| | | ENGS 36 Chemical Engineering |
| | Group 3 | ENGS 37 Introduction to Environmental Engineering |
| | | ENGS 41 Sustainability and Natural Resources Management |
| | | ENGS 43 Environmental Transport and Fate |
| | | ENGS 44 Sustainable Design |
| | | ENGS 52 Introduction to Operations Research |
| | Group 4 | ENGS 56 Introduction to Biomedical Engineering |
| | | Any ENGS course numbered above 20 (excluding ENGS 80 and 87) |

continued

ENGINEERING SCIENCES MAJOR MODIFIED WITH PUBLIC POLICY cont.

| REQUIRED COURSES | |
|--|---|
| Public Policy (choose 4 with at least 1 from each group) | Group 1 |
| | PBPL 5 Introduction to Public Policy |
| | PBPL 40 Economics of Public Policymaking |
| | PBPL 41 Writing and Speaking Public Policy |
| Group 2 | PBPL 42 Ethics and Public Policy |
| | PBPL 43 Social Entrepreneurship |
| | PBPL 45 Introduction to Public Policy Research |
| Group 3 | ECON 20 Econometrics |
| | Any course (excluding Engineering Sciences) from a policy track, such as Environment and Public Policy, Health and Public Policy, Natural Resources and Public Policy, Science/Technology and Public Policy |
| Culminating experience | Thesis, design project, or advanced course (see page 18) |

For advice, contact Dean Joseph Helble. Information on Public Policy courses and tracks is at: rockefeller.dartmouth.edu/minor

* May not be taken under the Non-Recording Option (NRO).

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH STUDIO ART

| PREREQUISITES | | |
|---|---|-----------|
| Mathematics | MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions | 3 courses |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses |
| Chemistry | CHEM 5 General Chemistry | 1 course |
| Computer Science (choose 1 option) | ENG 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | 1 course |
| REQUIRED COURSES | | |
| Engineering core courses | ENG 21 Introduction to Engineering** ENG 22 Systems ENG 24 Science of Materials ENG 33 Solid Mechanics | 4 courses |
| Engineering electives | Any 2 engineering sciences courses available for AB credit in the major. | 2 courses |
| Studio Art core courses | SART 15 Drawing I SART 16 Sculpture I | 2 courses |
| Studio Art electives | Any upper level Studio Art course | 2 courses |
| Culminating experience | Thesis, design project, or advanced course (see page 18) | |

For advice, contact Professor Peter Robbie.

* May not be taken under the Non-Recording Option (NRO).

** Should be taken sophomore year.

ENGINEERING SCIENCES MINOR

Students should note that many Engineering Sciences courses require prerequisites in addition to those noted. No courses other than those used as prerequisites to the minor may be taken under the Non-Recording Option to satisfy requirements of the minor.

| PREREQUISITES | | |
|---------------------------------|--|-----------|
| Mathematics | MATH 3 Introduction to Calculus | 3 courses |
| | MATH 8 Calculus of Functions of One and Several Variables | |
| | MATH 13 Calculus of Vector-Valued Functions | |
| Physics | PHYS 13 Introductory Physics I | 2 courses |
| | PHYS 14 Introductory Physics II | |
| REQUIRED COURSES | | |
| Core courses | ENG 20 Introduction to Scientific Computing, OR COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming | 3 courses |
| | ENG 21 Introduction to Engineering | |
| | ENG 22 Systems | |
| Electives (choose 2) | Any engineering sciences undergraduate course numbered above 20 (excluding 80 and 87) | 2 courses |

For advice, contact the chair of Engineering Sciences, Professor Erland Schulson.

HUMAN-CENTERED DESIGN MINOR

The minor in Human-Centered Design is an interdisciplinary program focused on the process of innovation for addressing human needs.

| PREREQUISITES | | |
|---|---|-----------|
| Design Foundation | ENG 12 Design Thinking ENG 21 Introduction to Engineering* | 2 courses |
| REQUIRED COURSES | | |
| Ethnographic Methods and Human Factors (Psychology) | ANTH 3 Intro to Cultural Anthropology | |
| | ANTH 18 Intro to Research Methods in Cultural Anthropology | |
| | ANTH 56 Intro to Research Methods in Medical Anthropology | |
| | SOCY 11 Research Methods | |
| | GEOG 11 Qualitative Methods and the Research Process in Geography | |
| | PSYC 21 Perception | |
| | PSYC 22 Learning | |
| | PSYC 23 Social Psychology | |
| | PSYC 27 Cognitive Neuroscience | |
| | PSYC 28 Cognition | |
| | PSYC 40 Intro to Computational Neuroscience | |
| | PSYC 43 Emotion | |
| Design electives | PSYC 51.11 Thinking About Thinking | |
| | ENG 18 Systems Dynamics in Policy Design and Analysis | |
| | ENG 44 Sustainable Design | |
| | ENG 75 Product Design** | |
| | COSC 27 Projects in Digital Arts | |
| | COSC 28 Advanced Projects in Digital Arts | |
| | COSC 67 Introduction to Human-Computer Interaction | |
| | FILM 51 Game Design | |
| | PBPL 43 Social Entrepreneurship | |
| | SART 65 Architecture I | |

Students may petition the department to substitute relevant courses in section 2 (that cover ethnographic methodology or human factors psychology) and 3 (that focus on problem-solving of human needs and result in the creation of artifacts). Before taking courses in section 3, it is recommended that students complete both courses in section 1 plus at least one course from section 2.

For advice contact Professor Peter Robbie (Engineering Sciences) or Professor Lorie Loeb (Computer Science).

* Should be taken sophomore year.

** For Engineering Majors: If ENG 75 is selected for the minor, it may not be counted toward the major.

MATERIALS SCIENCE MINOR

The departments of Chemistry, Physics, and Engineering Sciences offer the minor in Materials Science, which can be combined with majors in any of the three areas.

| PREREQUISITES | | | | | | | | |
|---|---|-----------|---|---------|--|---------|--|-----------|
| Chemistry | CHEM 5-6 General Chemistry | 2 courses | | | | | | |
| Physics | PHYS 13, 14 Introductory Physics I, II | 2 courses | | | | | | |
| REQUIRED COURSES | | | | | | | | |
| Core course | ENGS 24 Science of Materials | 1 course | | | | | | |
| Required course (choose 1) | PHYS 76 Methods of Experimental Physics ENGS 133 Methods of Materials Characterization | 1 course | | | | | | |
| Electives (choose 2, each from a different group) | <table border="1"> <tr> <td>Group 1</td> <td>ENGS 131 Science of Solid State Materials PHYS 73 Condensed Matter Physics I</td> </tr> <tr> <td>Group 2</td> <td>CHEM 108 Chemistry of Macromolecules: Physical Properties and Characterization CHEM 109 Chemistry of Macromolecules: Synthesis and Characterization</td> </tr> <tr> <td>Group 3</td> <td>ENGS 73 Materials Processing and Selection ENGS 132 Thermodynamics and Kinetics in Condensed Phases PHYS 43 Statistical Physics</td> </tr> </table> | Group 1 | ENGS 131 Science of Solid State Materials PHYS 73 Condensed Matter Physics I | Group 2 | CHEM 108 Chemistry of Macromolecules: Physical Properties and Characterization CHEM 109 Chemistry of Macromolecules: Synthesis and Characterization | Group 3 | ENGS 73 Materials Processing and Selection ENGS 132 Thermodynamics and Kinetics in Condensed Phases PHYS 43 Statistical Physics | 2 courses |
| Group 1 | ENGS 131 Science of Solid State Materials PHYS 73 Condensed Matter Physics I | | | | | | | |
| Group 2 | CHEM 108 Chemistry of Macromolecules: Physical Properties and Characterization CHEM 109 Chemistry of Macromolecules: Synthesis and Characterization | | | | | | | |
| Group 3 | ENGS 73 Materials Processing and Selection ENGS 132 Thermodynamics and Kinetics in Condensed Phases PHYS 43 Statistical Physics | | | | | | | |

Note: If ENGS 137 is taken as a general requirement, at least one elective must be taken from outside the Engineering Sciences department.

For advice, contact the chair of Engineering Sciences, Professor Erland Schulson.

OTHER MAJOR MODIFIED WITH ENGINEERING SCIENCES

Any major can be modified with Engineering Sciences. Students should note that many Engineering Sciences courses require prerequisites in addition to those noted. No electives may be taken under the Non-Recording Option.

| PREREQUISITES | | |
|----------------------------|--|-------------|
| Mathematics | MATH 3 Introduction to Calculus | 2 courses |
| | MATH 8 Calculus of Functions of One and Several Variables | |
| Physics | PHYS 13 Introductory Physics I (or PHYS 3-4)* | 1-2 courses |
| REQUIRED COURSES | | |
| Core courses (choose 1) | ENG 21 Introduction to Engineering** | 1 course |
| | ENG 22 Systems | |
| Electives (choose 3) | Any engineering sciences course numbered above 20 (excluding 80 and 87) | 3 courses |

For advice, contact the chair of Engineering Sciences, Professor Erland Schulson, and the chair of the department of the major.

* Must have been taken at Dartmouth. AP credit not permitted.

** Should be taken sophomore year.

Bachelor of Engineering (BE)

engineering.dartmouth.edu/academics/undergraduate/be

The Bachelor of Engineering (BE) program is a professional engineering program accredited by the Engineering Accreditation Commission of ABET.

abet.org

PROGRAM EDUCATIONAL OBJECTIVES

The BE degree program at Thayer School seeks to produce engineers who, during the first few years after graduation:

- Apply interdisciplinary breadth to professional activities;
- Demonstrate innovation in professional activities;
- Practice effective teamwork and written and verbal communication;
- Initiate the process of lifelong learning; and
- Serve society at large.

To achieve these objectives, the outcomes upon graduation from the program are that all of its students will have the ability to:

- Apply mathematics, science, engineering science and methods to the analysis of problems;
- Synthesize solutions to engineering problems through creative design;
- Function effectively in a multidisciplinary professional environment; and
- Apply technology as responsible citizens.

ENROLLMENT

The number of students in the BE Program over the last few years has been:

- 2017–2018: 58 students
- 2016–2017: 81 students
- 2015–2016: 58 students
- 2014–2015: 82 students
- 2013–2014: 97 students

GRADUATION

Over the past 3 years, 97% of BE students completed graduation requirements within the standard time for the degree.

RESIDENCY

Completion of the BE program after the AB degree generally requires between one and 3 terms at Thayer School depending on courses taken during the first 4 years. Advanced standing on entry to Dartmouth may shorten the overall time required; some students complete both the AB and BE in 4 years.

NUMBER OF COURSES

The BE degree requires a minimum of 9 courses beyond the requirements for the AB degree. At least 6 courses must have significant engineering design content.

BE REQUIREMENTS

BE students take required courses and electives in mathematics, basic science, engineering sciences, and engineering design. Students can plan their AB and BE degree programs using the following chart.

| | | |
|--|---|--------------|
| Mathematics and basic science | MATH 3, 8, 13; or 11 | 9 courses |
| | PHYS 13, 14 | |
| | CHEM 5 | |
| | ENGS 91, 92, or 93 2 non-introductory courses chosen from ASTR 15 and above; BIOL 12 and above (except 52); CHEM 6, 10 and above (except 63); EARS 31, 33, 35, 37, 40-52, 59, 62, 64, 66-76, 79 and above; ENVS 30 and 79; MATH 17-29, 31, 32, 35, 38, 39, 40, 42, 43, 50 and above; PHYS 19 or 40 (formerly 24), 41 and above (except 48); COSC 30/ENGS 66, COSC 31, 35, 39, 40, 49, 71, 73, 74; PSYC 21, 40, 45, 46, 65 | |
| Engineering common core | ENGS 20 (counts as 0.5 course for BE credit) ENGS 21, 22, 23 | 3.5 courses |
| Engineering distributive core (choose 2) | ENGS 24, 25, 26, 27 | 2 courses |
| Engineering gateway (choose 2 from 2 different disciplines) | ENGS 31 or 32, ENGS 33 or 34, ENGS 30, 35 or 36, ENGS 37 | 2 courses |
| Engineering electives (choose 6) | 3 courses must form a coherent disciplinary concentration* with 1 of these having significant design content; the remaining 3 electives may be chosen from ENGS or ENGG courses numbered 24-88 (except 66, 75, 87), 103, 107-177, 192 and 199; COSC 50-84 (except 30, 31, 35, 39, 40, 49, 71, 73, 74) and COSC 170-276 (except 174, 179, 189, 210). Two of the 3 electives may be mathematics or natural science courses as listed above. | 6 courses |
| Capstone engineering design | ENGS 89/90 (Prior to enrollment in ENGS 89, at least 6 engineering courses must be completed. These include ENGS 21 plus 5 additional courses numbered 22 to 76 [excluding 75] and 91 and above.) | 2 courses |
| Total | | 24.5 courses |

Detailed information about specific courses that satisfy accreditation and Thayer School requirements is in the Bachelor of Engineering Program Plan, available at dartmouth.edu/bannerstudent

NOTE: The only BE courses that can be taken under the Non-Recording Option are MATH 3, 8, 13; PHYS 13, and CHEM 5.

* With the exception of one of either ENGS 34 (prerequisites 20, 22, 23, 25) or ENGS 36 (prerequisites 20, 22, 25), courses to be included in the area of "three-course concentration" will be numbered above ENGS/ENGG 40 and will require at least one prerequisite either from the series ENGS 20-37 or from advanced courses within the sciences. With permissions, suitable advanced science courses may count within the three-course concentration. To include ENGS 86 or 88 in the three-course concentration, a proposal, which includes prerequisite courses, a syllabus, learning objectives and what principles of engineering will be mastered, needs to be submitted in advance (before the fourth week of the term prior to which ENGS 86 or 88 will be taken) and approved by the BE Committee. The computer science courses permitted in the three-course concentration are COSC 50, 55-83 (except 56, 71, 73, 74). The excluded courses COSC 51, 56, and 84 may be used as engineering electives. Although the requirement is a three-course concentration, students are encouraged to enroll in four courses in their area of concentration.

BE ADVISORS

Students can find a BE advisor in a concentration matching their interests at:
<http://engineering.dartmouth.edu/academics/undergraduate/be/advisors>

Dual-Degree Program

engineering.dartmouth.edu/academics/undergraduate/dual

The dual-degree program provides an opportunity for students at other liberal arts colleges to take engineering courses at Dartmouth. Students spend their junior or senior year on exchange at Dartmouth, return to their home school for graduation, and then return to Dartmouth for a second year to complete the BE program.

Sample AB/BE Programs

engineering.dartmouth.edu/academics/undergraduate/be/samples

Students interested in focusing their AB/BE studies in a specific engineering discipline may review online sample programs in the following fields:

- Biological Engineering
- Biomedical Engineering
- Chemical Engineering
- Computer Engineering
- Electrical Engineering
- Energy Engineering
- Environmental Engineering
- Materials Science and Engineering
- Mechanical Engineering

Undergraduate Admissions

AB ADMISSIONS

Admission to the AB program is through the Dartmouth Admissions Office, McNutt Hall, Hanover, NH 03755.

www.dartmouth.edu/admissions

BE ADMISSIONS

Admission Requirements

Dartmouth students finishing an AB degree with a major or modified major in Engineering Sciences are automatically admitted to the BE program, pending submission of an approved BE program plan and BE student information form.

Students with an accredited degree in engineering from other colleges and universities are eligible for admission.

Students with a bachelor's degree that is substantially equivalent to the Dartmouth AB in Engineering Sciences plus two upper-level electives in engineering, mathematics, or the natural sciences are also eligible for admission.

Students with minor deficiencies may be admitted but will be required to complete additional undergraduate course work.

Students who need more than one full term (3 courses) are required to enroll initially as special students.

Special Students: Students who do not meet requirements for admission to the BE program may be admitted as special students. Students who need no more than the equivalent of one term to satisfy prerequisites will be considered for admission as regular degree candidates.

Part-Time Students: Residents of the Upper Valley region who have a BS in engineering or an appropriate math/science program and can meet basic academic requirements may pursue coursework on a part-time basis.

Application Procedure

Current Dartmouth students and dual-degree students can download an electronic copy of the application from:

engineering.dartmouth.edu/academics/admissions/undergraduate/be

Students from other colleges and universities can receive an application through the mail by emailing:

engineering.admissions@dartmouth.edu

Prospective students from the U.S. and Canada can call toll-free:

1-888-THAYER6 [1-888-842-9376]

Prospective students from other parts of the world should call:

1-603-646-2606

Completed applications, with supporting documents, should be mailed or emailed to:

Engineering Admissions
Thayer School of Engineering
Dartmouth College
14 Engineering Drive
Hanover, NH 03755-8000
engineering.admissions@dartmouth.edu

Application deadline: 2 terms prior to the beginning term of the BE program. The BE program plan is submitted to the BE Program Committee at the time of application.

Tuition and Expenses

Tuition for the 2018–2019 academic year is \$17,832 per term, which covers instruction, use of instructional facilities, and health care service through the College infirmary.

Students without their own hospital coverage must purchase a Dartmouth College hospital insurance policy for approximately \$3,000 per year.

The total cost of a year in the BE program, including tuition, books, room, board, and incidentals, will be approximately \$69,000–70,000 for the academic year 2018–2019. Financial aid can significantly lower the yearly cost.

Financial Aid

Full-time students in the BE program are eligible for need-based aid in the form of partial-tuition scholarships, hourly employment as teaching assistants or in other capacities, fellowships, and loans. Special and part-time students are not eligible for financial aid.

The assessment of need is based on the PROFILE application at:

profileonline.collegeboard.com

Awards are made annually on an academic year basis. Financial aid information is available at:

engineering.dartmouth.edu/academics/admissions/financial-aid

HOURLY TEACHING ASSISTANTSHIPS AND OTHER EMPLOYMENT

Teaching assistants positions may be available to well qualified students. A teaching assistant is paid hourly to assist with grading, problem sessions, and/or lab work.

Assignments are made on a term-by-term basis. Other limited hourly employment is also available to qualified students.

Normally work is limited to no more than 12 hours per week during academic terms and 40 hours per week between terms and during off-terms. Hourly employment may not exceed a total of 40 hours per week from any and all College sources.

PARTIAL TUITION SCHOLARSHIPS

Grants applicable to tuition charges are awarded on the basis of need, as demonstrated by the PROFILE application. Acceptance of a partial tuition scholarship will require a student to serve as a teaching assistant, if called upon. Scholarships are renewed each academic year contingent upon continued satisfactory academic progress.

LOANS

B.E students are eligible to apply for federal Stafford Loans, federal Perkins Loans, and DELC Loans through the Dartmouth Financial Aid Office. Educational loan applicants must complete and submit a Free Application for Federal Student Aid (FAFSA) form. This form may be obtained at:

fafsa.ed.gov

Registration

RESIDENCY

BE candidates enrolled in 2 or more courses are considered full-time students and as being in residence.

CHECK-IN

All students intending to be in residence must check in at the beginning of each term (see Academic Calendar, page 2) through an on-line check-in process. This practice lets the faculty and administration know who is actually in residence for the new term and facilitates contacting students with individual problems.

A \$50 penalty will be charged for late check-in (10 days after check-in day). A student who, for good reason, must check in late may petition the registrar for waiver of this charge.

All College financial accounts must be settled prior to check-in. A student who has failed to settle financial accounts will not be allowed to check in.

COURSE CHANGES

Check-in has no direct connection with the changing of courses. Registered students may change courses through the Internet (using the student "Banner" home page) or at the Office of the Registrar. Each term, a 5-day period is available for adding, dropping, or exchanging courses; no approval is needed. If possible, students should arrange their course load during this period.

During the second 5 class days of a term a student may add or exchange courses by requesting an instructor override for the intended new courses.

WITHDRAWAL

Courses. Until 2 weeks before the last class of the term, students may withdraw from a course at their own discretion. A student needing to withdraw must obtain the instructor's signature on a drop form and submit it to the registrar before the deadline indicated each term. The course remains on the student's transcript with the notation "W," for "withdrew."

Degree Programs. A student may withdraw (i.e., terminate residence) from degree candidacy at any time. If a student withdraws during the first 10 class days, the notation "withdrew for the term, in good standing" will be entered on the transcript. If withdrawal occurs after the first 10 class days, with certification by the instructor of each course that the student is in good standing, the notation "withdrew for the term, in good standing" will be entered on the transcript; otherwise, each course will be entered followed by the notation "withdrew."

Withdrawal for medical reasons, when verified by the student's physician, will be entered as such. Students who withdraw from degree candidacy and later wish to resume degree candidacy must petition the director of their degree program in writing for re-admission.

REFUND POLICY

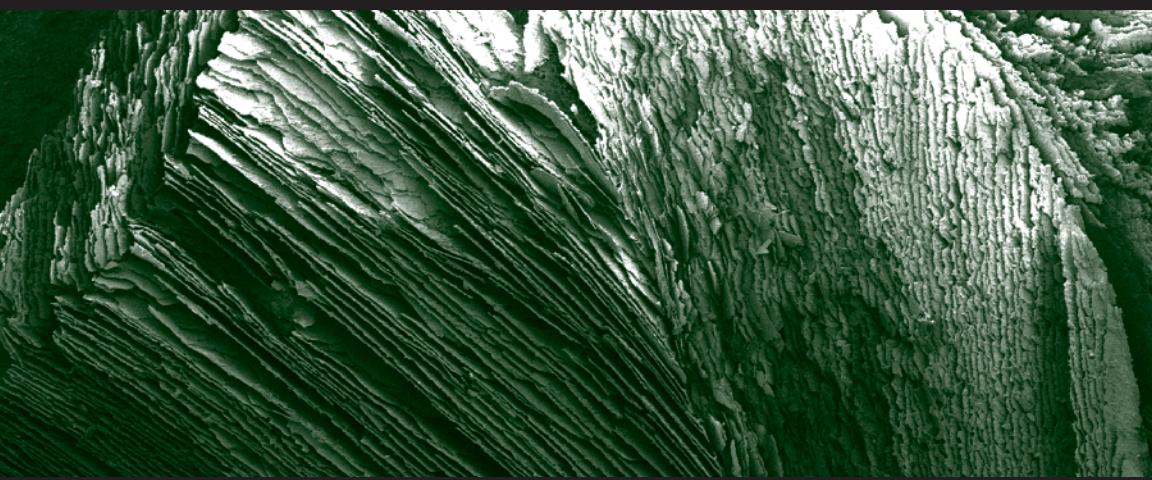
The Thayer School policy on refund of payments by students who withdraw voluntarily or are dismissed from the School during any term is as follows:

Tuition. A full refund is issued to students who withdraw or are dismissed before the beginning of term classes. During the first week, the refund is 90%; during the second and third weeks, 75%; during the fourth week, 50%; during the fifth week, 25%. After the fifth week, there is no refund.

Requests for refunds should be submitted in writing to the Controller of Dartmouth College, 6132 McNutt Hall, Room 103, Hanover, NH 03755, (603) 646-3230. Any balance due the student will be paid within 40 days.

undergraduate studies

Graduate Studies



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Aligned alumina platelets. Imaged by scanning electron microscope by PhD candidate Danielle Castley, working in Professor Ulrike Wegst's lab.

Graduate Studies

Master of Engineering Management (MEM)

mem.dartmouth.edu

The Master of Engineering Management (MEM) program is a professional degree program that combines engineering and management courses taught by faculty from Thayer School and Tuck School of Business. Graduates of the program are engineers who understand the business of technology.

CURRICULUM

The curriculum integrates engineering, mathematics, and core management courses. Electives typically are engineering and management courses, but students may also choose courses from Dartmouth's other graduate science departments, Geisel School of Medicine, The Dartmouth Institute, or from Vermont Law School.

Each student develops a program of study, which is submitted to and approved by the MEM Director during the student's first term of residence and updated each term of progress through the program.

PREREQUISITES

A Bachelor's degree is required. MEM students generally hold an undergraduate degree in engineering or one of the physical sciences.

ACADEMIC HONOR

All students, upon matriculation, sign a statement that they agree to abide by the honor principles and Student Conduct Code established by Dartmouth College. A full statement appears in the student handbook, which students receive during registration.

RESIDENCY

Students must be in residence for a minimum of 3 academic terms.

NUMBER OF COURSES

The number of courses required depends on the student's preparation. Students entering the program from a college other than Dartmouth generally take 14 courses, including the summer industry internship. Dartmouth students, including dual-degree students who have taken the BE at Thayer School, may count ENGS 93 Statistical Methods in Engineering toward the MEM degree, even if it is taken as part of the AB and/or BE requirements. With the exception of ENGM 387, four-course loads, for courses to be used in satisfaction of the MEM requirements, must be pre-approved by the MEM Director.

INTERNSHIP

Students participate in an industry internship to satisfy the ENGG 390 Master of Engineering Management Project, usually in the summer term. Students register for ENGG 390 in the term in which the work is done. A course fee applies.

GRADE STANDARDS

The grade assigned at the completion of any graduate-level course is one of the following:

| GRADE | EQUIVALENT | INDICATES |
|----------------|------------|---|
| HP (High Pass) | A, A- | Distinctly superior work |
| P (Pass) | B+, B, B- | Good work |
| LP (Low Pass) | C+, C, C- | Work deficient but acceptable for graduate credit |
| CR (Credit) | Passing | Satisfactory work (in courses, where HP, P, or LP grade assignment is inappropriate; not intended as alternative to HP, P, or LP) |
| NC (No Credit) | D, E | Unsatisfactory work, not acceptable for graduate credit |

No fewer than 14 courses in total, with no fewer than 12 P or HP grades, may be submitted in satisfaction of MEM degree requirements. Students who earn LP or lower in courses that satisfy degree requirements receive a letter of warning from the director of their graduate program. A detailed statement on the Student Probation Policy is available from the registrar.

INDUSTRY PARTNERS

MEM students have several opportunities to work with practicing engineers and engineering managers. In the first fall term technology assessment course (ENGM 178), student teams develop a thorough assessment of an assigned technology topic area. Each team works with faculty and, when feasible, an industry partner in the analysis of the technology. Over the 12 weeks between assignment definition and final deliverable, the student teams present their on-going work to professional managers and engineers on review boards.

The ENGG 390 Master of Engineering Management Project is tied to an internship in industry. The internship may focus on engineering or management or both, with students presenting their results to a professional review board upon completion of the project. MEM Program Options

MEM COURSE REQUIREMENTS

| | | |
|---|--|------------|
| Professional skills | ENGM 387 MEM Professional Skills | 1 course |
| Applied mathematics | ENG 93 Statistical Methods in Engineering ENGM 184 Introduction to Optimization Methods | 2 courses |
| Engineering project/design sequence | ENGM 178 Technology Assessment ENGG 390 MEM Project/Internship | 2 courses |
| Management core courses | ENGM 179 Accounting ENGM 180 Corporate Finance ENGM 181 Marketing ENGM 183 Operations Management | 4 courses |
| Data and decisions (choose at least 1) | ENGG 103 Operations Research ENGM 182 Data Analytics | 1 course |
| Engineering management electives (choose at least 1) | ENGG 103 Operations Research ENG 157 Chemical Process Design ENG 171 Industrial Ecology ENGM 182 Data Analytics ENGM 185 Topics in Manufacturing Design and Processes ENGM 186 Technology Project Management ENGM 187 Technology Innovation and Entrepreneurship ENGM 188 Law for Technology and Entrepreneurship ENGM 190 Platform Design, Management, and Strategy | 1 course |
| MEM free electives (choose 3) | Any graduate engineering sciences or engineering course Business and management courses from Tuck School* Graduate courses from Dartmouth science departments Courses from Geisel School of Medicine Environmental law courses from Vermont Law School | 3 courses |
| TOTAL | | 14 courses |

* MEM tuition covers 2 courses from Tuck School; extra tuition will be charged for additional courses.

Typical Course Sequence—MEM Only

The following is the typical program for a student with an ABET-accredited BS degree in engineering or its equivalent from a school other than Dartmouth. Students who do not hold an accredited degree may be required to take additional courses.

| | |
|---------------|---|
| Fall | ENGM 178 Technology Assessment ENGM 181 Marketing ENGM 184 Introduction to Optimization Methods ENGM 387 MEM Professional Skills |
| Winter | ENG 93 Statistical Methods in Engineering ENGM 179 Accounting MEM free elective |
| Spring | ENGM 180 Corporate Finance ENGM 183 Operations Management MEM free elective or ENGM 182 Data Analytics |
| Summer | ENGG 390 MEM Project/Internship |
| Fall | MEM free elective or ENGG 103 Operations Research Engineering management elective MEM free elective |

Typical Course Sequence—Combined BE/MEM

Dartmouth AB graduates who majored in Engineering Sciences will normally complete the BE degree before completing the MEM degree. Since ENGS 93 from either the AB or BE degree programs may be counted toward the MEM degree, Dartmouth students typically complete the MEM degree with 13 courses beyond the BE degree. During the AB years, students should take two engineering sciences electives beyond what is required for the major.

| AB YEARS | |
|--|--|
| 2 engineering sciences electives beyond what is required for the major | |
| BE YEAR | |
| Fall | ENGS 89 Engineering Design Methodology and Project Initiation (BE requirement) |
| | ENGM 178 Technology Assessment |
| | ENGM 387 MEM Professional Skills |
| | Engineering sciences elective |
| Winter | ENGS 90 Engineering Design Methodology and Project Completion (BE requirement) |
| | ENGS 93 Statistical Methods in Engineering |
| | Engineering sciences elective |
| Spring | 2 engineering sciences electives |
| | 1 MEM free elective |
| MEM YEAR | |
| Summer | ENGG 390 MEM Project/Internship |
| Fall | MEM free elective or ENGG 103 Operations Research |
| | ENGM 181 Marketing |
| | ENGM 184 Introduction to Optimization Methods |
| Winter | ENGM 179 Accounting |
| | 2 MEM free electives |
| Spring | ENGM 180 Corporate Finance |
| | ENGM 183 Operations Management |
| | MEM free elective or ENGM 182 Data Analytics |

MEM PROGRAM OPTIONS

Students have the option to target their MEM studies toward a specific field of interest. Five possible focus areas are listed below with corresponding elective courses from which students may choose in order to complete their MEM program.

Healthcare Systems Focus

Students interested in applying engineering management and systems engineering to the healthcare industry may choose electives offered at Thayer School, Tuck School of Business, and The Dartmouth Institute for Health Policy & Clinical Practice (TDI). Additionally, they may choose an internship at a hospital or healthcare company to complete the ENGG 390 project. The opportunity to explore independent study and research projects associated with The Dartmouth Center for Health Care Delivery Science is also available to students. Examples of MEM healthcare electives:

ENGS 160 Biotechnology and Biochemical Engineering
ENGS 165 Biomaterials
ENGS 167 Medical Imaging
ENGS 169 Intermediate Biomedical Engineering
ENGM 189 Medical Device Development (.5 credit)
ENGG 199 Medical Diagnostics and Monitoring
TDI: ECS 111 Critical Issues in Health and Health Care
TDI: ECS 115 Strategic & Financial Management of Health Care Institutions
TDI: ECS 121 Decision and Cost-Effective Analysis: An Introduction
Tuck School: Business of Healthcare
Tuck School: Contemporary Issues in Biotechnology
Tuck School: International Health Systems
Tuck School: Investing and Deal Making in Healthcare
Tuck School: Management of Healthcare Organizations
Tuck School: Medical Care and the Corporation
Tuck School: Structure, Organization, and Economics of the Healthcare Industry

Energy and Environmental Focus

Students interested in applying engineering management to energy and environmental concerns may choose electives offered at Thayer School, Tuck School of Business, and environmental law courses offered at Vermont Law School located in South Royalton, Vermont. Additionally, they may choose to accept an internship at an energy or environmental company to complete the ENGG 390 project. Examples of MEM energy and environmental electives:

ENGS 171 Industrial Ecology
ENGS 172 Climate Change and Engineering
ENGG 173 Energy Utilization
ENGG 174 Energy Conversion
ENGS 175 Energy Systems
ENGG 261 Biomass Energy Systems
Tuck School: Business and Climate Change
Tuck School: Energy Economics
Vermont Law School: Energy Law and Policy in a Carbon-Constrained World
Vermont Law School: Energy Regulation, Markets and the Environment
Vermont Law School: Renewable Energy Law and Policy

Operations and Analytics Focus

Students interested in operations management and applying analytics tools may choose electives offered at Thayer School or the Tuck School of Business. Additionally, they may choose to accept an internship at a manufacturing company or undertake project to improve operations within a company to complete the ENGG 390 project. Examples of MEM Operations and Analytics electives:

ENGM 182 Data Analytics

ENGM 185 Topics in Manufacturing Design and Processes

ENGM 186 Technology Project Management

Tuck School: Database Marketing

Tuck School: Data Mining for Business Analytics

Tuck School: Management of Service Operations

Tuck School: Operations Strategy

Tuck School: Professional Decision Modeling

Tuck School: Tools for Improving Operations

Entrepreneurial Focus

Students interested in starting a high-technology company might choose entrepreneurial electives offered at Thayer School and Tuck School of Business. Additionally, they may choose an entrepreneurial internship or project for ENGG 390. Practical experience can be gained by working with Thayer School professors who have patented their work and established successful businesses. Strategic advice, mentoring, and networking information are available through the Dartmouth Entrepreneurial Network. Examples of MEM entrepreneurial electives:

ENGM 187 Technology Innovation and Entrepreneurship

ENGM 188 Law for Technology and Entrepreneurship

ENGM 190 Platform Design, Management, and Strategy

Tuck School: Building Entrepreneurial Ventures

Tuck School: Entrepreneurial Finance

Tuck School: Entrepreneurial Thinking

Tuck School: Entrepreneurship and Innovation Strategy

Tuck School: Entrepreneurship in the Social Sector 1

Tuck School: Entrepreneurship in the Social Sector 2

Tuck School: Leading Entrepreneurial Organizations

Management of Design Focus

Students interested in applying engineering management and systems engineering studies toward preparation in managing technology design efforts (e.g., in the fields of chemical process design, electronics design, product design, and mechanical design) may choose appropriate electives offered at Thayer School or Tuck School of Business. In addition, they may choose an ENGG 390 internship that is focused on design and/or management of design. Examples of MEM management of design electives:

ENG 125 Power Electronics and Electromechanical Energy Conversion

ENG 126 Analog Integrated Circuit Design

ENG 128 Advanced Digital System Design

ENG 146 Computer-Aided Mechanical Engineering Design

ENG 157 Chemical Process Design

ENG 158 Chemical Kinetics and Reactors

ENG 171 Industrial Ecology

ENGG 173 Energy Utilization

ENGG 176 Design for Manufacturing

ENGM 186 Technology Project Management

Note that upper division engineering sciences courses such as ENG 44, 65, 73, 75, and 76, coupled with extra faculty-supervised student work, can also count toward the management of design focus area.

Duke University Exchange

Thayer School MEM students may choose to spend their second fall term at Duke University taking equivalent courses in Duke's Master of Engineering Management program.

MEM PROGRAM DIRECTORS

Geoffrey G. Parker, Director
Professor of Engineering

Ross A. Gortner
Associate Director

MEM FACULTY

Eric Bish
Visiting Assistant Professor

Laurens Debo
Associate Professor of Business Administration, Tuck School of Business

Jeremy Faludi
Assistant Professor of Engineering

Eric R. Fossum
Professor of Engineering

Oliver Goodenough
Adjunct Professor of Engineering
Professor, Vermont Law School

Ronald C. Lasky
Professor of Engineering
Director, Cook Engineering Design Center

Felipe Severino
Assistant Professor of Business Administration, Tuck School of Business

Eesha Sharma
Associate Professor of Business Administration, Tuck School of Business

Philip Stocken
Professor of Accounting, Tuck School of Business

Vikrant Vaze
Assistant Professor of Engineering

Master of Engineering (MEng)

Biomedical Track

engineering.dartmouth.edu/academics/graduate/meng

The Master of Engineering (MEng) program is designed around tracks centered on professional areas of activity and intended for engineers already in the profession seeking to add depth to their knowledge or acquire new specialized knowledge. The MEng program currently offers a biomedical track. New tracks will be developed in the future.

The MEng program:

- can be completed in 3 terms
- is course-based
- does not require the completion of a thesis

Candidates for the degree acquire:

- Basic competency in applied mathematics and engineering
- Breadth of engineering knowledge through elective courses
- Depth of engineering through courses specific to the track

MEng students are responsible for tuition charges (see page 76). Students have the option of completing all the requirements in 3 terms, taking 3 courses at a time, or following a schedule that fits their professional obligations.

QUALIFICATION FOR ADMISSION

Applicants with an accredited bachelor's level degree in engineering or with bachelor's level degrees in scientific fields such as physics, chemistry, and computer sciences are encouraged to apply. The background engineering knowledge and skills of applicants without an accredited bachelor level engineering degree will be considered on a case-by-case basis by the admissions committee. Non-holders of accredited engineering degrees may be required to take the necessary prerequisite courses in addition to the requirements of the MEng degree.

ACADEMIC HONOR

All students, upon matriculation, are required to attend a series of workshops in ethics and sign a statement that they agree to abide by the honor principles established by Dartmouth College. A full statement of academic honor is at:

graduate.dartmouth.edu/services/regulations.html

RESIDENCY AND PROGRAM DURATION

The residency requirement of the MEng is flexible, and is fulfilled through course attendance. It is expected that most students will want to complete the program in 3 terms, taking 3 courses at a time. However, students who want to work on their MEng over the course of a few years, taking one course at a time, for example, will also have the ability to enroll in the program. Students must complete the MEng program within 6 years of initial enrollment.

NUMBER OF COURSES

The program's basic requirement consists of 9 courses. Students enrolled in the MEng program are expected to follow one pre-defined specialization track. A selection of courses is offered, from which students must choose 5. An additional 4 courses can be selected from other offerings at Thayer School or other departments at Dartmouth College. Within their first week of enrollment students are required to submit a course plan to be approved by the MS-PhD Committee. Students enrolled in the MEng program who are not holders of accredited engineering degrees will likely need to take additional courses including courses at the undergraduate level, with the specifics determined on a case-by-case basis at the time of enrollment. Thayer School's BE or AB students may not double count courses towards the MEng degree.

GRADE STANDARDS

With the exception of the thesis, the grade assigned at the completion of any graduate-level course is one of the following:

| GRADE | EQUIVALENT | INDICATES |
|----------------|------------|---|
| HP (High Pass) | A, A- | Distinctly superior work |
| P (Pass) | B+, B, B- | Good work |
| LP (Low Pass) | C+, C, C- | Work deficient but acceptable for graduate credit |
| CR (Credit) | Passing | Satisfactory work (in courses, where HP, P, or LP grade assignment is inappropriate; not intended as alternative to HP, P, or LP) |
| NC (No Credit) | D, E | Unsatisfactory work, not acceptable for graduate credit |

No more than one LP grade for every 6 courses may be submitted in satisfaction of master's degree requirements. Any student who earns LP or lower in courses that satisfy degree requirements receives a letter of warning from the director of his or her graduate program. A detailed statement on the Student Probation Policy is available from the registrar.

ADVISORS

A faculty advisor aids each student in developing a program, which is submitted to and approved by the MS-PhD Committee during the student's first term of residency.

BIOMEDICAL ENGINEERING TRACK

Students must select a total of 9 courses from those offered at Thayer or possibly at Dartmouth. **Five of the courses should be from the list below.** The remaining four electives may be chosen from any graduate level ENGS/ENGG courses or suitable alternatives with advisor approval. For students with no engineering background, additional courses may be required. Upon being admitted into the program, within the first week, students are to submit a MEng Program Course Plan to the program director.

- ENGS 111 Digital Image Processing
- ENGS 129 Biomedical Circuits and Systems
- ENGS 160 Biotechnology and Biochemical Engineering
- ENGS 161 Metabolic Engineering
- ENGS 162 Basic Biological Circuit Engineering
- ENGS 163 Advanced Protein Engineering
- ENGS 165 Biomaterials
- ENGG 166 Quantitative Human Physiology
- ENGS 167 Medical Imaging
- ENGG 168 Biomedical Radiation Transport
- ENGS 169 Intermediate Biomedical Engineering
- ENGS 170 Neuroengineering
- ENGG 365 Advanced Biomaterials

ADDITIONAL GUIDELINES

Students enrolling in the MEng program will not be allowed to transition to the MEM program. Students enrolled in the MS or PhD programs may not transition to the MEng program, unless their faculty advisor initiates the request. Some students showing promise may be allowed to enroll into the MS or PhD programs with the approval of the MS-PhD Committee, and at the invitation of a faculty member willing to sponsor them.

Master of Science (MS)

engineering.dartmouth.edu/academics/graduate/ms

The Master of Science in Engineering Sciences program stresses innovative engineering research, advanced levels of engineering skills, and extensive project management experience. Candidates for the degree acquire:

- basic competency in applied mathematics and engineering
- breadth of engineering knowledge through taking a range of courses
- depth of engineering knowledge through focused research as well as courses

Arrangement of a thesis research topic must be done with an individual faculty member who will sponsor the student in the program.

In the tradition of founder Sylvanus Thayer, graduate students are encouraged to participate in service activities, such as those sponsored by the Thayer Council.

RESEARCH

engineering.dartmouth.edu/research

Engineering research at Dartmouth reflects our belief that innovation happens at the intersection of disciplines and our emphasis on addressing areas of critical human need.

Students may pursue research in any of the following categories.

- Biological & Chemical Engineering
- Electrical & Computer Engineering
- Energy
- Engineering in Medicine
- Materials Science & Engineering
- Mechanical & Systems Engineering

PREREQUISITES

A bachelor's degree is required; MS students generally hold their degree in engineering or one of the physical sciences.

ACADEMIC HONOR

All students, upon matriculation, are required to attend a series of workshops in ethics and sign a statement that they agree to abide by the honor principles established by Dartmouth College. A full statement of academic honor is at:

graduate.dartmouth.edu/services/regulations.html

RESIDENCY

Students are required to be in residence a minimum of 3 terms.

NUMBER OF COURSES

Students entering the program with an accredited bachelor's degree in engineering are required to take 6 graduate-level courses beyond any graduate courses taken for the BE

Students entering the program without an accredited bachelor's degree in engineering are required to complete 9 graduate-level courses beyond any graduate courses taken for the bachelor's degree, with a minimum of 5 courses in engineering.

Courses taken previously, e.g., as an undergraduate, can be used in satisfaction of the degree requirements, but do not reduce the total number of courses required unless admission is with advanced standing.

GRADE STANDARDS

With the exception of the thesis, the grade assigned at the completion of any graduate-level course is one of the following:

| GRADE | EQUIVALENT | INDICATES |
|----------------|------------|---|
| HP (High Pass) | A, A- | Distinctly superior work |
| P (Pass) | B+, B, B- | Good work |
| LP (Low Pass) | C+, C, C- | Work deficient but acceptable for graduate credit |
| CR (Credit) | Passing | Satisfactory work (in courses, where HP, P, or LP grade assignment is inappropriate; not intended as alternative to HP, P, or LP) |
| NC (No Credit) | D, E | Unsatisfactory work, not acceptable for graduate credit |

No more than one LP grade for every 6 courses may be submitted in satisfaction of master's degree requirements. Any student who earns LP or lower in courses that satisfy degree requirements receives a letter of warning from the director of his or her graduate program. A detailed statement on the Student Probation Policy is available from the registrar.

ADVISORS

A faculty advisor aids each student in developing a program, which is submitted to and approved by the Thayer School Graduate Program Committee during the student's first term of residency.

MS COURSE OPTIONS

| | | |
|--|---|--------------------|
| Applied mathematics (choose at least 1) | ENGS 91 Numerical Methods in Computation ENGS 92 Fourier Transforms and Complex Variables ENGS 93 Statistical Methods in Engineering ENGS 100 Methods in Applied Mathematics I ENGS 105 Computational Methods for Partial Differential Equations I ENGS 106 Numerical Linear Algebra | 1 or more courses |
| Engineering depth (choose at least 3) | Courses in the area of the student's research should be chosen to increase the student's depth of expertise and knowledge. These courses should be chosen in concert with the thesis advisor from the graduate engineering listings. | 3 or more courses* |
| Engineering breadth (choose at least 2) | The remainder of the courses may be any graduate course listing area, with approval of the thesis advisor and the graduate program committee. | 2 or more courses* |
| | Research leading to a written thesis | |
| | An oral defense of the thesis | |

* Engineering Management courses are not permitted.

MS THESIS REQUIREMENTS

The MS thesis demonstrates a depth of knowledge in a specific field of engineering research or design. A thesis committee typically consists of 3 Dartmouth faculty members (including the student's thesis advisor); one of the 3 may be from outside the program of study.

The candidate also presents a public oral defense of the thesis, which is conducted by the candidate's thesis committee. The candidate is responsible for giving final, signature-ready copies of the thesis to each committee member to review at least two weeks prior to the defense. Also, the candidate must submit an electronic notice of the defense to the Registrar two weeks in advance for distribution to the faculty and for posting.

A hard copy and a pdf of the thesis must be submitted to the registrar for archiving. Copyright to the thesis is held by the Trustees of Dartmouth College.

DUAL DEGREES

BE/MS

Students who wish to be awarded the BE degree simultaneously with the MS must have taken a substantial portion of the undergraduate program at Dartmouth or in one of its official exchange programs. Students should plan their programs to satisfy both the MS requirements and the ABET criteria for the BE, and discuss their plans with the MS program director.

At least one term prior to the scheduled MS thesis defense, the BE/MS candidate submits to the Registrar a BE program plan approved by both his/her advisor and the Director of the BE program.

MEM/MS

Students who want to qualify in both research and the practical application of engineering and management may earn the MS and MEM degrees simultaneously by completing all the requirements of both degrees.

A separate application to the MEM program is required; the student should work out course choices and funding plans for each degree. Interested students should contact the director of the MEM program.

MD/MS

engineering.dartmouth.edu/academics/graduate/mdms

The MD/MS program, offered by Thayer School and Geisel School of Medicine, is designed for people who intend to pursue clinical practice and want to develop research skills in a related engineering area. It is also well suited to students who want to better understand technologies they will employ as practicing physicians. The program provides a funded research experience in engineering that is expected to lead to a research publication and provides practice in engineering design and analysis.

Applicants must hold an undergraduate degree in engineering and meet the entrance requirements of each school. Application must be made to each school separately. MD students apply to Thayer School in the first, second, or third year of medical school and carry out their MS studies in the fourth and part of the fifth year. The schedule provides 12 months to complete the MS degree and preserves time in July and August following the third and fourth years for important Geisel School of Medicine activities. The MS program requires a minimum of 3 terms in residence at Thayer School.

| | |
|----------------------|--|
| Years 1 and 2 | Geisel School of Medicine |
| Year 3 | Geisel School of Medicine (through August) |
| Year 4 | Thayer (September–June) |
| Year 5 | Geisel School of Medicine (July–August) Thayer (September–November) Geisel School of Medicine December–June) |

MD/MS COURSE OPTIONS

| | | |
|---|--|-----------|
| Applied mathematics (choose 1) | ENGS 91 Numerical Methods in Computation ENGS 92 Fourier Transforms and Complex Variables ENGS 93 Statistical Methods in Engineering ENGS 100 Methods in Applied Mathematics I ENGS 105 Computational Methods for Partial Differential Equations I ENGS 106 Numerical Linear Algebra | 1 course |
| Engineering courses (choose 2) | ENGS 110 Signal Processing ENGS 130 Mechanical Behavior of Materials ENGS 131 Science of Solid State Materials ENGS 132 Thermodynamics and Kinetics in Condensed Phases ENGS 150 Computational Fluid Dynamics ENGS 155 Intermediate Thermodynamics ENGS 156 Heat, Mass, and Momentum Transfer ENGS 161 Metabolic Engineering ENGS 162 Basic Biological Circuit Engineering ENGS 167 Medical Imaging | 2 courses |
| Engineering electives (choose 3) | Select 3 additional graduate engineering courses | 3 courses |
| | Research leading to a written thesis | |
| | An oral defense of the thesis | |

Doctor of Philosophy (PhD)

engineering.dartmouth.edu/academics/graduate/phd

Thayer PhD students acquire technical depth in their chosen area of concentration while simultaneously gaining a breadth of knowledge in related fields. In addition to courses in applied mathematics and engineering, students undertake a multi-year research project, usually part of a larger multidisciplinary project. These research projects are negotiated with a faculty mentor who sponsors the student in the program.

In the tradition of founder Sylvanus Thayer, graduate students are encouraged to participate in service activities, such as those sponsored by the Thayer Council.

Students interested in entrepreneurship can augment their program with the **PhD Innovation Program**, which adds courses that address technology business practices and the art of moving research discoveries to market. Students in this program meet all requirements, including passing an oral qualifying examination and defending a PhD thesis proposal. Specific requirements for the candidates in the Innovation Program are on page 69.

RESEARCH

engineering.dartmouth.edu/research

Engineering research at Dartmouth reflects our belief that innovation happens at the intersection of disciplines and our emphasis on addressing areas of critical human need.

Students may pursue research in any of the following categories.

- Biological & Chemical Engineering
- Electrical & Computer Engineering
- Energy
- Engineering in Medicine
- Materials Science & Engineering
- Mechanical & Systems Engineering

PREREQUISITES

The foundation for doctoral work is undergraduate preparation in science, mathematics, and engineering principles. Applicants must hold a bachelor's or master's degree to be considered for the program. Students who are not prepared to complete the first-year requirements (see page 63) are advised to enter the Thayer School MS program and petition later to be admitted to the PhD program. Students who have prior graduate training may be considered for advancement to candidacy after completing one or 2 terms of the first-year doctoral program.

ACADEMIC HONOR

All students, upon matriculation, are required to attend a series of workshops in ethics and sign a statement that they agree to abide by the honor principles established by Dartmouth College. A full statement of academic honor is at: graduate.dartmouth.edu/services/regulations.html

RESIDENCY

Students in the PhD program are expected to spend at least 9 terms in residence, 3 of which will take place after successfully completing the oral qualifying examination.

NUMBER OF COURSES

The program of study is developed based on each student's background and professional interests in consultation with the advisor and first year advisory committee. Students are required to take 8 to 10 courses, reflecting the distribution in the table below. Students with prior graduate credits may transfer up to 50% of the courses they plan to take to count towards this requirement.

| | |
|--|-------------|
| Applied mathematics | 2-3 courses |
| Courses directed toward acquiring breadth of knowledge in engineering sciences | 2-3 courses |
| Courses leading to a depth of knowledge in an engineering specialty | 4 courses |

In addition to engineering and applied mathematics courses, PhD students participate in the following seminars and discussion with the visiting speakers:

| | |
|---|----------|
| ENGG 195 Seminar on Science, Technology and Society | 4 terms |
| ENGG 197 PhD Professional Workshops | 1 term |
| ENGG 198 Research-in-Progress Workshop | annually |

GRADE STANDARDS

With the exception of the dissertation, the grade assigned at the completion of any graduate-level course is one of the following:

| GRADE | EQUIVALENT | INDICATES |
|----------------|------------|---|
| HP (High Pass) | A, A- | Distinctly superior work |
| P (Pass) | B+, B, B- | Good work |
| LP (Low Pass) | C+, C, C- | Work deficient but acceptable for graduate credit |
| CR (Credit) | Passing | Satisfactory work (in courses, where HP, P, or LP grade assignment is inappropriate; not intended as alternative to HP, P, or LP) |
| NC (No Credit) | D, E | Unsatisfactory work, not acceptable for graduate credit |

No more than one LP grade for every 6 courses may be submitted in satisfaction of the degree requirements. Any student who earns LP or lower in courses that satisfy degree requirements receives a letter of warning from the director of his or her graduate program. A detailed statement on the Student Probation Policy is available from the registrar.

FIRST-YEAR PROGRAM PLAN

During the first year of the PhD program, students prepare for formal candidacy by taking courses and participating in faculty-directed research projects.

Each student works with a faculty advisor and 2 additional Thayer faculty members.

This group helps each student develop a first-year program of study, which the student submits to the Graduate Programs Office during the first week of the term. A typical first-year program of study includes:

| | |
|--|-----------|
| Graduate-level courses completed with a grade of B or higher (can be a combination of Dartmouth courses and courses taken at another institution beyond BS or BE degree requirements) | 6 courses |
| ENGG 296 Graduate research completed with a grade of B or higher | 3 terms |

During the first term, the faculty help the student develop a full program plan to fulfill the PhD requirements, which the student submits to the Graduate Program Office before the beginning of the second term.

FULL PROGRAM PLAN

The PhD program plan includes the remaining engineering courses required plus participation in the following seminars and workshops:

| | |
|---|--|
| ENGG 195 Seminar on Science, Technology and Society | 4 terms |
| ENGG 197 PhD Professional Workshops | 1 term (usually taken in one of the latter years in residence) |
| ENGG 198 Research-in-Progress Workshop | Annual participation during spring break |

ANNUAL PHD ADVISOR MEETING REPORT

At the end of each year, students undergo a meeting review of their grades, goals, achievements and future plans in research, formal coursework, and extracurricular activities. Following the first year meeting, before the fall of second year, the advisor provides the Registrar a written report describing a student's annual performance. Following a positive outcome of this first annual meeting, the student is expected to complete the oral qualifier examination before the end of the fall term. The second annual meeting should also occur at the end of the student's second year, and a successful outcome of this would allow the student to progress to the PhD thesis proposal presentation before the end of the third year. Every year that a student remains registered in the PhD program, an annual review meeting and report must be completed. Students who are not progressing in the normal manner are transferred to the MS program with the understanding that they may later request to be reconsidered as PhD candidates.

PHD CANDIDACY YEARS

Once advanced to PhD candidacy, students work with a special advisory committee to make sure that all degree requirements are met. In broad terms, the requirements include:

| REQUIREMENT | DEFINITION | DEMONSTRATED BY | SEE PAGE |
|--------------------------------|---|---|----------|
| Technical proficiency | Knowledge of the principles and methods of engineering, applied science, and applied mathematics underlying the anticipated thesis research | Coursework and oral qualifying examination | 65 |
| Technical breadth | Knowledge of one or more areas outside of or secondary to the candidate's main area of specialization | Program of study OR presentation of research proposal OR a project in an area outside main area of specialization | 66 |
| Specialization | Mastery of knowledge in the chosen area of research | Presentation of a thesis proposal AND a program of study | 67 |
| Professional competence | Ability to develop resources in chosen area of research | ENGG 197 PhD Professional Workshops | 67 |
| Original research | Significant contribution to engineering knowledge combined with professional expertise in the chosen area of study | Presentation at a professional meeting, manuscript accepted for publication, dissertation, oral defense | 67 |

Technical Proficiency: Oral Qualifying Examination

The oral qualifying exam (ENGG 194), a set of questions put forward by an oral examination committee to the candidate, normally takes place before or during the 5th term of the student's program, or in exceptional circumstances early in the 6th term. The exam is open to the faculty, but not to the general public.

The committee tests the candidate's knowledge of principles and methods underlying the field in which advanced work is to be performed. The exam covers material selected by the candidate's advisor in consultation with the examining committee and includes coverage of mathematical techniques appropriate to the research area. The structure of the preparation for the examination is flexible. See details at:

engineering.dartmouth.edu/images/uploads/OralQualifyingExam-Details.pdf

The student prepares a description of the planned exam, obtains signatures of the advisor and committee members, and submits this to the graduate program office at least 1 month prior to the exam date.

The examination committee consists of 4 members – the Chair plus 3 Dartmouth faculty examiners, with at least 2 of the examiners from Thayer School. A Thayer faculty member other than the student's advisor chairs the committee. This chair is assigned by the MS-PhD Director. See details at:

engineering.dartmouth.edu/images/uploads/OralQualifyingExam-Details.pdf

The examination committee gives the student a pass, fail or conditional pass result. Students who fail may retake the oral examination—one time only—within the following 3 months. Upon passage of the exam or fulfillment of the conditions of the conditional pass (before the assigned deadline) and with a letter of support from the advisor, the student is admitted to PhD candidacy pending vote by the Thayer School faculty.

Technical Breadth

The faculty advisor helps the candidate plan a demonstration of technical breadth, which is approved by the Graduate Program Committee. The plan details one of the following options:

| | |
|----------|--|
| Option 1 | A set of courses, taken for credit, outside or secondary to the candidate's principal area of specialization |
| Option 2 | A focused set of courses, taken for credit, which creates a secondary emphasis in specialization and may involve independent study or research |
| Option 3 | Presentation of a research proposal OR an oral examination in an area outside the main area of specialization. The candidate might present a research seminar on the topic with an examination committee of 3 faculty members probing the candidate's depth of knowledge of the secondary area. This option may be combined with the ENGG 197 PhD Professional Workshops (pages 67). Students who do not pass may be permitted to take the oral examination—one time only—within the following 3 months. |
| Option 4 | A creative design project, completed within a time limit of approximately 30 days, in an area outside the main area of specialization. The project is defined and the candidate's performance is evaluated by a committee of 3 faculty members appointed by the program director. The committee gives the student a statement of need, and the student proposes a means of satisfying that need in an effective, elegant, and economic manner. The project should display the candidate's ability to conceive and evaluate alternative solutions; carry out analytical evaluations at levels of approximation suited to the problem and the time limit; and recognize situations in which experimental work is needed. If the time limit prohibits experimentation, the candidate should devise the appropriate experiments and demonstrate how the expected results would aid in the design. Within the 30-day time limit, the candidate submits a written report plus an executive summary. Following an oral presentation of the project, the committee examines and evaluates the candidate's performance in the project. Students who do not pass may be permitted to revise and resubmit the report—one time only—within the following 3 months. |

Specialization: Thesis Proposal

The candidate demonstrates mastery of an area of specialization by writing and presenting a thesis proposal within the first 18 months of candidacy. A thesis committee, approved by the director of the PhD program, advises the candidate on the proposed thesis research and administers the presentation of the thesis proposal.

The PhD Examination committee consists of a minimum of 3 full-time Dartmouth faculty members of which a minimum of 2 must be from the Thayer School (including the dissertation advisor) as well as an external member with a faculty equivalent research appointment outside of Dartmouth. The external member may participate in meetings in person or via video conference.

The candidate's proposal—a public presentation of the proposed thesis research—explains the scope and importance of the proposed research and plans for its completion. The presentation should be understandable, at least in a general way, to students and faculty not in the subject area.

Two weeks before the presentation, candidates must:

- submit the thesis proposal in writing to their committee.
- submit an electronic copy of the thesis proposal notice to the Thayer registrar for distribution to the faculty and for posting.

Students who do not pass may be permitted to present the proposal—one time only—within the following 3 months.

Professional Competence: PhD Professional Workshops

The candidate demonstrates professional competence by completing ENGG 197 PhD Professional Workshops, which is offered each winter term by the faculty and outside experts. The workshop emphasizes skills in completing competitive proposals, business funding, patenting, research team organization, teaching, résumé and CV creation, and job search techniques. The candidate generally completes the workshop in one of the latter years in residence.

Each candidate completes a competitive research proposal or a business plan for critique by 2 expert referees selected from among faculty, outside experts, and/or corporate representatives.

Candidates who have submitted a competitive research proposal to a funding agency or a business plan to a venture capitalist or financial institution prior to completing the workshop may petition to have the proposal or business plan fulfill this requirement.

Original Research

Candidates demonstrate their significant contribution to engineering knowledge and professional expertise in the chosen area of study by performing original research. The PhD Examination committee consists of a minimum of 3 full-time Dartmouth faculty members of which a minimum of 2 must be from the Thayer School (including the dissertation advisor) as well as an external member with a faculty equivalent research appointment outside of Dartmouth. The external member may participate in meetings in person or via video conference.

The research is reviewed through all of the following means:

| | |
|----------------------|--|
| Presentation | Elements of the research presented at a professional meeting with the candidate as first author |
| Dissertation | Written abstract followed by detailed explanation of the research, approved and signed by the PhD thesis committee |
| Oral defense* | Presentation of the dissertation in a forum open to the public |
| Paper | Elements of the research accepted for publication with the candidate as first author |

* The candidate is responsible for giving final, signature-ready copies of the thesis to each committee member to review at least two weeks prior to the defense. Also, the candidate must submit an electronic notice of the defense to the Registrar two weeks in advance for distribution to the faculty and for posting.

DISSERTATION ARCHIVING

A hard copy and a pdf of the final dissertation must be submitted to the registrar for archiving. Copyright to the dissertation is held by the Trustees of Dartmouth College.

CAREER DEVELOPMENT

Thayer School offers PhD candidates optional training in engineering management, development and design, and teaching through ENGG 197 and through Thayer Career Services.

Engineering Management

Candidates interested in administration, management, and/or organization may obtain an Engineering Management Certificate by completing any 3 of the following Engineering Management courses:

ENGM 179 Accounting
ENGM 180 Corporate Finance
ENGM 181 Marketing
ENGM 182 Data Analytics
ENGM 183 Operations Management
ENGM 185 Topics in Manufacturing Design and Processes
ENGM 186 Technology Project Management
ENGM 187 Technology Innovation and Entrepreneurship
ENGM 188 Law for Technology and Entrepreneurship
ENGM 190 Platform Design, Management, and Strategy

Candidates may enroll in other Thayer School engineering management courses or, for additional tuition, courses offered by Tuck School.

Engineering Development and Design

Candidates interested in industrial engineering design and development may elect a 2-term course sequence in design methodology and/or an individual project course.

ENGs 89/90 Engineering Design Methodology
ENGG 390 Master of Engineering Management Project

Teaching

Candidates interested in teaching may serve as teaching assistants for one of the undergraduate and graduate courses that has a problem session, tutorial, or laboratory component. In special cases, a candidate may participate in the design and development of laboratory exercises for lecture courses or in the design and development of a special topics course.

Candidates may apply for one of these positions only with permission of their advisor.

More formalized teacher training programs, offered through the Dartmouth Center for the Advancement of Learning, are open to Thayer School PhD candidates.

More information at:

dartmouth.edu/~dcal

PhD Innovation Program

engineering.dartmouth.edu/academics/graduate/phd/innovation

Students in the PhD Innovation Program fulfill all the requirements listed previously for first-year PhD students and PhD candidates. Once admitted to candidacy, the student works with a special advisory committee to make sure that all the requirements for the Innovation Program are met. These include:

| | | |
|--|---|----------------------------------|
| Skills development | ENGG 195 Seminar on Science, Technology, and Society ENGG 197 PhD Professional Workshops (recommended but not required; can be used to write a Small Business Innovation Research [SBIR] proposal) ENGG 198 Research in Progress Workshop (annual participation) | 4 terms recommended annual |
| Applied mathematics (choose 2) | ENGS 91 Numerical Methods in Computation ENGS 92 Fourier Transforms and Complex Variables ENGS 93 Statistical Methods in Engineering ENGS 100 Methods in Applied Mathematics I ENGS 105 Computational Methods for Partial Differential Equations I ENGS 106 Numerical Linear Algebra | 2 courses |
| Engineering depth | Courses in the area of the student's research, chosen to increase the student's depth of expertise and knowledge. These courses should be selected in concert with the thesis advisor. | 4 courses |
| Innovation elective (choose at least 1) | Any graduate-level technical course in area outside the student's area of core expertise ENGM 179 Accounting | 1 course |
| Innovation coursework | ENGM 180 Corporate Finance ENGM 187 Technology Innovation and Entrepreneurship ENGM 188 Law for Technology, and Entrepreneurship (or equivalent course) ENGG 321 Introduction to Innovation | 3 courses |
| Internship | ENGG 300 Students will work in a start-up company (possibly their own) or an R&D department in their general field(s) of interest for up to six months. Prior to starting the Internship, students must see Lori Laventure (111 Cummings) to discuss financial/insurance issues. | |

The Innovation track includes all the original research requirements of the PhD
See page 67.

PhD Innovation Program Training in Surgical Innovation

[engineering.dartmouth.edu/academics/graduate/innovation/
surgical-training-track/](http://engineering.dartmouth.edu/academics/graduate/innovation/surgical-training-track/)

Training in Surgical Innovation (TSI), a specialized option of the PhD Innovation Program, offers a unique research environment and optimal scale for preparing trainees for careers in original surgical technology research with an emphasis on innovations aimed at improving the safety and outcomes of surgical procedures. The program brings an organized, systematic approach to address unsolved problems in surgery, rather than leave them to chance or trial-and-error.

TSI students must satisfy all requirements of the PhD Innovation Program—technical proficiency, technical breadth, specialization, professional competence, original research and innovation skills development—plus training tailored to the surgical setting, including ENGS 325: Introduction to Surgical Innovation and a surgical innovation internship.

TSI's three program directors—Professors Keith Paulsen, Sohail Mirza MD, and Eric Fossum—and nearly 50 faculty members provide mentorship in:

- biomedical engineering
- surgical translation
- innovation and entrepreneurship

Each trainee is assigned three mentors—one from each of area of expertise—for guidance through the program.

CENTER FOR SURGICAL INNOVATION

Trainees have access to experienced clinician-scientists and operating rooms equipped with intraoperative advanced three-dimensional imaging capability at Dartmouth-Hitchcock's Center for Surgical Innovation (CSI). Prioritized for research, CSI houses twin ORs that share 3T MRI and 64-slice CT scanners, which move into the ORs for use during surgical procedures. Adjacent diagnostic rooms allow imaging studies to occur immediately prior to surgery or minimally invasive interventional procedures to take place independent of surgery. The larger OR also offers robotic angiography and a surgical table that rotates 270 degrees, allowing MR, CT, and fluoroscopy to occur during the same case.

INNOVATION & ENTREPRENEURSHIP

Trainees work directly with experienced entrepreneurs to develop intellectual property and commercialization pathways providing unprecedented opportunities to translate ideas rapidly from bench to practice in the surgical setting. They learn to accelerate the progression of ideas from the early phases of prototype development, to small-scale testing and validation, to large-scale comparative effectiveness evaluation, commercialization, and dissemination into practice.

More specifically, TSI students learn to recognize opportunities for innovation and entrepreneurship in surgery driven by compassionate and careful evaluation of unmet patient needs and rigorous analysis of suboptimal patient outcomes, rather than simply by market opportunities. TSI provides trainees with the skills and training necessary to pursue careers in biomedical engineering innovation and entrepreneurship in industry as well as academia.

CROSS-COLLABORATION

TSI trainees interact with colleagues from Dartmouth's Geisel School of Medicine, Dartmouth-Hitchcock's Departments of Surgery, Orthopaedics, Family Medicine, and The Dartmouth Institute for Health Policy and Clinical Practice, as well as Dartmouth's Tuck School of Business through its Health Care Initiative and Center for Private Equity and Entrepreneurship.

TSI trainees also take advantage of three NIH research programs at Dartmouth:

1. National Center for Advancing Translational Sciences (NCATS) award for the Dartmouth Clinical and Translational Science Institute (SYNERGY);
2. National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS) Multidisciplinary Clinical Research Center in Musculoskeletal Diseases;
3. NIAMS Ruth L. Kirschstein National Research Service Award (NRSA) Orthopaedic Resident Clinician/Researcher Program

TIMELINE / FUNDING / OUTCOMES

Completion of the program takes approximately 4–5 years with various sources of financial support:

- Year 1: Funding from Thayer; basic coursework; surgical rotations class completed
- Year 2: Funding from TSI; limited coursework; Mentoring Committee formed; qualifying exams completed; thesis topic identified; research begins
- Year 3: Research continues
- Year 4/5: Research continues; Innovation Program internship defined; support usually provided by faculty grants or institutional funds (during the Innovation Program internship)

Trainees challenge and advance current understanding in biomedical engineering areas of interest to participating faculty or define a new initiative that has the full endorsement of participating faculty.

Graduates of TSI will:

- Have the scientific/engineering training required to engage in original research at the level expected of a post-doctoral fellow in biomedical engineering;
- Be exposed to multiple surgical procedures and specialties similar to a medical student participating in surgical rotations;
- Gain understanding of innovation and entrepreneurship at a level approximating an MBA student interested in the biomedical industry.

ADMISSIONS

Trainees will be selected from applicants to Thayer's PhD Innovation Program expressing interest in TSI. Admissions criteria include:

1. Evidence of participation in multi-disciplinary and/or non-traditional learning opportunities;
2. Demonstration of creativity and/or motivation and passion for translational research, innovation and entrepreneurship through specific extra-curricular activities;
3. Articulation of a strong rationale for pursuing TSI.

Students may also apply to the PhD Innovation Program TSI during their first or second year of regular PhD program study at Thayer, but are advised to consult with their advisor, Professor Paulsen, and Professor Fossum prior to applying.

MD/PhD in Biomedical Engineering

geiselmed.dartmouth.edu/mdphd
engineering.dartmouth.edu/academics/graduate/md

The MD/PhD Program in Biomedical Engineering combines the medical curriculum at Geisel School of Medicine with the PhD program at Thayer School. Students must apply to Geisel School of Medicine as well as Thayer School, indicating their specific interests. Both degrees are awarded simultaneously after typically 7 to 8 years of study.

PREREQUISITES

The foundation for doctoral work is undergraduate preparation in science, mathematics, and engineering principles. Applicants must hold a bachelor's or master's degree to be considered for the MD/PhD program.

ACADEMIC HONOR

All students, upon matriculation, are required to attend a series of workshops in ethics and sign a statement that they agree to abide by the honor principles established by Dartmouth College. A full statement of academic honor is at:
graduate.dartmouth.edu/services/regulations.html

RESIDENCY

MD/PhD candidates are in residence at Thayer School a minimum of 6 terms, including 4 terms of participation in ENGG 195 Seminar on Science, Technology, and Society.

NUMBER OF COURSES

The candidate with undergraduate engineering training (BE or BS degree) plus 2 years of medical school training normally takes:

| | |
|---|-----------|
| Applied mathematics | 3 courses |
| Engineering courses leading to a depth of knowledge in an engineering specialty | 4 courses |

In addition to engineering and applied mathematics courses, PhD students participate in the following seminars and workshops:

| | |
|---|----------|
| ENGG 195 Seminar on Science, Technology and Society | 4 terms |
| ENGG 197 PhD Professional Workshops | 1 term |
| ENGG 198 Research-in-Progress Workshop | annually |

COURSE OF STUDY

| | |
|------------------------------|--|
| Basic medical phase | Geisel School of Medicine Years 1 and 2 Up to 3 eight-week laboratory rotations |
| First-year PhD phase | Completion of 6 graduate engineering courses |
| | Participation in 2 terms of ENGG 195 and one term of ENGG 198 |
| | Initiation of dissertation research with thesis advisor |
| | Qualification for PhD candidacy |
| Second-year PhD phase | Oral examination |
| | Completion of additional graduate courses |
| | Participation in 2 terms of ENGG 195 and one term of ENGS 198 |
| | Thesis proposal and dissertation research |
| Final PhD phase | Dissertation research |
| | Completion of thesis defense |
| Final medical phase | Geisel School of Medicine Years 3 and 4 |

DEGREE REQUIREMENTS

MD Requirements

Candidates complete the 4-year MD curriculum. The electives of Year 4 may be fulfilled through PhD dissertation research.

PhD Requirements

| REQUIREMENT | DEFINITION | DEMONSTRATED BY | SFF PAGE |
|--------------------------------|---|---|----------|
| Technical proficiency | Knowledge of the principles and methods of engineering, applied science, and applied mathematics underlying the anticipated thesis research | Coursework and oral qualifying examination | 65 |
| Technical breadth | Knowledge of one or more areas outside of or secondary to the candidate's main area of specialization | Years 1 and 2 of Geisel School of Medicine curriculum | 66 |
| Specialization | Mastery of knowledge in the chosen area of research | Presentation of thesis proposal approved by MD/ PhD Biomedical Engineering Committee | 67 |
| Professional competence | Ability to develop resources in chosen area of research | ENGG 197 PhD Professional Workshops | 67 |
| Original research | Significant contribution to engineering knowledge combined with professional expertise in the chosen area of study | Presentation at a professional meeting, manuscript accepted for publication, dissertation, oral defense | 67 |

Graduate Admissions

engineering.dartmouth.edu/academics/admissions/graduate

ADMISSION REQUIREMENTS

MEM Program

Prospective students for the MEM program should have an accredited bachelor's degree in engineering. Students with a bachelor's degree in a physical science may be admitted on condition that any undergraduate deficiencies be made up through additional coursework.

Graduates of programs other than the Dartmouth College AB and the Thayer School Dual-Degree program must submit scores from the Graduate Record Exam (GRE). Students whose native language is not English must also submit evidence of satisfactory completion of Test of English as a Foreign Language (TOEFL) or the International English Language Testing System (IELTS) scores.

MEng Program

Prospective students for the MEng program should have an accredited bachelor's degree in engineering. Students with a bachelor's degree in a physical science may be admitted on condition that any undergraduate deficiencies be made up through additional coursework.

Graduates of programs other than the Dartmouth College AB and the Thayer School Dual-Degree program must submit scores from the Graduate Record Exam (GRE). Students whose native language is not English must also submit evidence of satisfactory completion of Test of English as a Foreign Language (TOEFL) or the International English Language Testing System (IELTS) scores.

MS and PhD Programs

Prospective students for the MS and PhD programs should have an accredited bachelor's degree in engineering, mathematics, or science. Students with minor program deficiencies may be admitted but will be required to complete undergraduate courses in addition to their graduate courses.

Graduates of programs other than the Dartmouth College AB and the Thayer School Dual-Degree program must submit scores from the Graduate Record Exam (GRE). Students whose native language is not English must also submit evidence of satisfactory completion of Test of English as a Foreign Language (TOEFL) or the International English Language Testing System (IELTS) scores.

Special Students: Students who do not meet prerequisite requirements for admission may be admitted as special students. However, when no more than the equivalent of one term's work is needed to satisfy prerequisites, students will be considered for admission as regular degree candidates.

Part-Time Students: Residents of the Upper Valley region who have a BS in engineering or an appropriate math/science program and can meet basic academic requirements may pursue coursework on a part-time basis. Thesis topics will be selected with the approval of a graduate program director.

APPLICATION PROCEDURE

Prospective students should review the application instructions and apply on-line:
engineering.dartmouth.edu/academics/admissions/graduate

For information, prospective students from the U.S. and Canada can call toll-free:
1-888-THAYER6 [1-888-842-9376]

Prospective students from other parts of the world should call:
1-603-646-2606

Supporting documents should be sent to:

Graduate Admissions
Thayer School of Engineering
Dartmouth College
14 Engineering Drive
Hanover, NH 03755-8000

engg.admissions@dartmouth.edu

Thayer Application Deadline: January 1 for the following fall term for MEng,
MS and PhD applicants. MEM applicants apply in “rounds” with January 15 as the
first deadline.

engineering.dartmouth.edu/academics/admissions/graduate

JOINT-DEGREE APPLICANTS

MD/MS and MD/PhD applicants must apply to both Thayer School and Geisel School
of Medicine.

Tuition and Expenses

Tuition for the 2018–2019 academic year is \$17,832 per term, which covers instruction, use of instructional facilities, and health care service through the College infirmary.

Students without their own hospital insurance must purchase a Dartmouth College hospital insurance policy for approximately \$3,000 a year.

The total cost of a year, including tuition, books, room, board, and incidentals, will be approximately \$69,000–70,000 for the academic year 2018–2019. Financial aid can significantly lower the yearly cost.

Financial Aid

For full-time students, Thayer School offers an array of financial aid, including tuition scholarships, fellowships, assistantships, loans, and hourly employment. Special and part-time students are ineligible for Thayer School financial aid.

All awards are contingent upon continued satisfactory performance and academic progress.

Students who want an educational loan must submit a completed “Free Application for Federal Student Aid” (FAFSA) form, downloadable from:

fafsa.ed.gov

More information is at:

engineering.dartmouth.edu/academics/admissions/financial-aid
or-graduate.dartmouth.edu/funding

FINANCIAL AID FOR MEM STUDENTS

MEM financial aid is need-based and is in the form of partial tuition scholarships. After the MEM internship or any leave term during the MEM program, the student is expected to contribute a minimum of \$3,000 toward tuition.

At the time of application, full-time applicants in the MEM program who are interested in applying for need-based aid must submit the PROFILE application available at:

profileonline.collegeboard.com

Awards are made annually on an academic year basis.

Hourly Teaching Assistantships and Other Employment. Teaching assistantships are available to well qualified students. A teaching assistant is paid hourly to assist with grading, problem sessions, and/or lab work. Assignments are made on a term-by-term basis. Other limited hourly employment is also available to qualified students.

Normally work is limited to no more than 12 hours per week during academic terms and 40 hours per week between terms and during off-terms. Hourly employment may not exceed a total of 40 hours per week from any and all College sources.

Partial Tuition Scholarships. Scholarships applicable to tuition charges are awarded on the basis of need, as demonstrated by the PROFILE application. Scholarships are renewed each academic year contingent upon continued satisfactory academic progress.

Loans. MEM students are eligible to apply for federal Stafford Loans, federal Perkins Loans, and DELC Loans through the Dartmouth Financial Aid Office. Application for educational loans requires submission of the Free Application for Federal Student Aid (FAFSA) and the Dartmouth Graduate Financial Aid application form (see above).

FINANCIAL AID FOR MS AND PHD STUDENTS*

Typically, an MS or PhD student enters Thayer School with full support on either a Research Assistantship or a Fellowship.

MS/PhD Stipends 2018–2019

Most MS and PhD financial aid includes full or partial tuition costs plus a monthly stipend.

| FINANCIAL AID | TUITION | STIPEND |
|--|--------------|-------------------|
| Research Assistantship for Master's or first-year PhD student | Full tuition | \$2,310 per month |
| Research Assistantship for PhD candidate | Full tuition | \$2,410 per month |
| Research Assistantship for PhD candidate who has passed the oral examination and the presentation of thesis proposal | Full tuition | \$2,510 per month |

Research Assistantships. Graduate research assistantships, funded by contract research, are available to well-qualified candidates enrolled in degree programs with thesis requirements. Graduate research assistantships normally carry an award of full tuition, a monthly stipend, and credit toward medical insurance if purchased through the College. Partial awards may also be made.

Research assistantship appointments extend over 3 to 4 terms and are made on recommendation of the contract principal investigator with the approval of the director of the MS and PhD programs. Graduate research assistants normally work in the area of their research interests and apply the results toward the thesis requirement.

Graduate research assistants may enroll in no more than 2 non-research courses in fall, winter, and spring terms. With the permission of the faculty advisor, enrollment in one non-research course is permitted in the summer term.

Graduate research assistants are expected to devote 20 hours per week to research when enrolled in 2 non-research courses, 30 hours per week when enrolled in one, and essentially full time between terms and when enrolled only for research. They are expected to be in residence full time, including between terms.

Since assistants are not regular employees of Dartmouth College, they do not earn vacation per se. However, College holidays apply to them. In addition, assistants may anticipate one-half week of time off for each academic term of appointment, to be arranged with their faculty advisor.

Although responsibilities are defined in terms of hours per week, the emphasis is on the quality of the student's performance. Continuation of any appointment into succeeding terms is conditional upon satisfactory performance and progress toward degree requirements.

Students who accept graduate assistantships may not engage in any additional employment outside or inside Thayer School without prior approval of the director of the MS and PhD programs. Such employment is usually limited to 10 hours per week.

Hourly Teaching Assistantships. Teaching assistantships are available to well qualified students. A teaching assistant is paid hourly to assist with grading, problem sessions, and/or lab work. Assignments are made on a term-by-term basis. Students who also hold graduate research assistantships or fellowships must have prior approval of the director of MS/PhD programs and their research advisors to accept an hourly teaching assistant position (or any other employment inside or outside Thayer School).

* Financial aid is available for MS and PhD students but not for MEng students.

Registration

RESIDENCY

Graduate students enrolled in 2 or more courses are considered full-time students and as being in residence.

CHECK-IN

All students intending to be in residence must check in at the beginning of each term (see Academic Calendar, page 2) through an on-line check-in process. This practice lets the faculty and administration know who is actually in residence for the new term and facilitates contacting students with individual problems.

A \$50 penalty will be charged for late check-in (10 days after check-in day).

A student who, for good reason, must check in late may petition the registrar for waiver of this charge.

All College financial accounts must be settled prior to check-in. A student who has failed to settle financial accounts will not be allowed to check in.

COURSE CHANGES

Check-in has no direct connection with the changing of courses. Registered students may change courses through the Internet (using the student "Banner" home page) or at the Office of the Registrar. Each term, a 5-day period is available for adding, dropping, or exchanging courses; no approval is needed. If possible, students should arrange their course load during this period.

During the second 5 class days of a term a student may add or exchange courses by requesting an instructor override for the intended new courses.

WITHDRAWAL

Courses. Until 2 weeks before the last class of the term, students may withdraw from a course at their own discretion. A student needing to withdraw must obtain the instructor's signature on a drop form and submit it to the registrar before the deadline indicated each term. The course remains on the student's transcript with the notation "W," for "withdrew."

Degree Programs. A student may withdraw (i.e., terminate residence) from degree candidacy at any time. If a student withdraws during the first 10 class days, the notation "withdrew for the term, in good standing" will be entered on the transcript. If withdrawal occurs after the first 10 class days, with certification by the instructor of each course that the student is in good standing, the notation "withdrew for the term, in good standing" will be entered on the transcript; otherwise, each course will be entered followed by the notation "withdrew."

Withdrawal for medical reasons, when verified by the student's physician, will be entered as such. Students who withdraw from degree candidacy and later wish to resume degree candidacy must petition the director of their degree program in writing for re-admission.

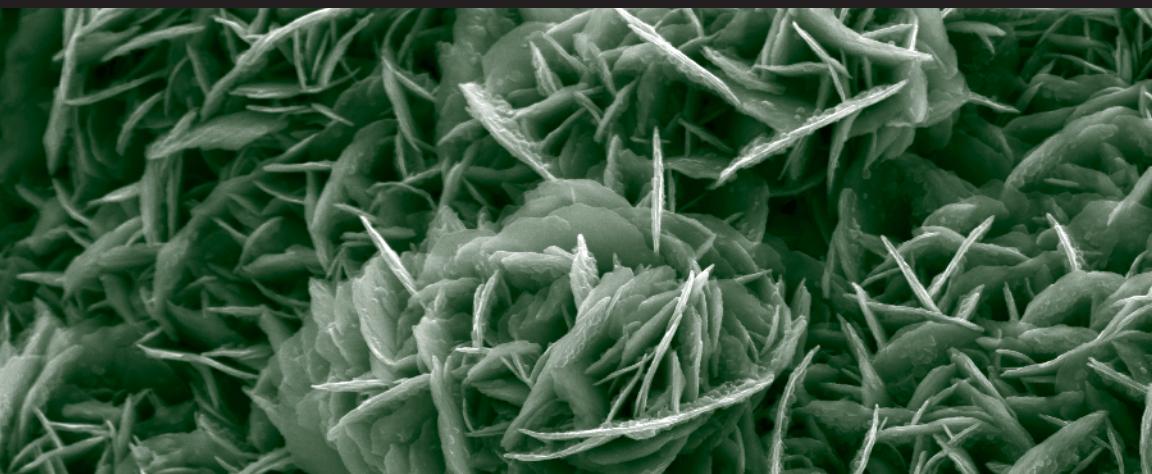
REFUND POLICY

The Thayer School policy on refund of payments by students who withdraw voluntarily or are dismissed from the School during any term is as follows:

Tuition. A full refund is issued to students who withdraw or are dismissed before the beginning of term classes. During the first week, the refund is 90%; during the second and third weeks, 75%; during the fourth week, 50%; during the fifth week, 25%. After the fifth week, there is no refund.

Requests for refunds should be submitted in writing to the Controller of Dartmouth College, 6132 McNutt Hall, Room 103, Hanover, NH 03755, (603) 646-3230. Any balance due the student will be paid within 40 days.

Undergraduate Courses



| | |
|---|-----|
| Undergraduate Courses by Category | 81 |
| Undergraduate Course Descriptions | 83 |
| Prerequisite Courses for Engineering Sciences | 103 |

Cu1.92S rose-petal-like nanoflakes are generated on the surface of copper foam immersed in sodium polysulfide solution overnight in an argon-filled glovebox. Imaged by scanning electron microscope by PhD candidate Chuanlong Wang, working in Professor Weiyang (Fiona) Li's lab.

Undergraduate Courses

engineering.dartmouth.edu/academics/courses/undergraduate

AB REQUIREMENTS

Most Engineering Sciences (ENGS) courses satisfy requirements for the Engineering Sciences major and can be used for AB credit.

DISTRIBUTIVE CODES

| | |
|-----|---|
| INT | International or Comparative Study |
| QDS | Quantitative and Deductive Science |
| SCI | Natural and Physical Science |
| SLA | Natural and Physical Science with Lab |
| TAS | Technology or Applied Science |
| TLA | Technology or Applied Science with Lab |
| TMV | Systems and Traditions of Thought, Meaning, and Value |

TERM OFFERED

| | |
|---|--------|
| F | Fall |
| W | Winter |
| S | Spring |
| X | Summer |

CLASS TIMES

The number or number-letter combination that follows the term abbreviation is explained in the timetable below. The x-period is time set aside for instructors to use as needed. For some courses, the x-period is an additional class session.

| | CLASS TIMES | X-PERIOD |
|-----|-------------------------------|---------------|
| 8 | MTuThF 7:45–8:35 | W 7:45–8:35 |
| 9S | MTuThF 9:05–9:55 | W 9:05–9:55 |
| 9L | MWF 8:50–9:55 | Th 9:05–9:55 |
| 10 | MWF 10:10–11:15 | Th 12:15–1:05 |
| 10A | TuTh 10:10–12:00 | W 3:30–4:20 |
| 11 | MWF 11:30–12:35 | Tu 12:15–1:05 |
| 12 | MWF 12:50–1:55 | Tu 1:20–2:10 |
| 2 | MWF 2:10–3:15 | Th 1:20–2:10 |
| 2A | TuTh 2:25–4:15 | W 4:35–5:25 |
| 3A | MTh M 3:30–5:20, Th 4:30–6:20 | M 5:35–6:25 |
| 3B | TuTh 4:30–6:20 | M 5:35–6:25 |
| 6A | MW 6:30–8:20 | |
| 6B | W 6:30–9:30 | |

The Dartmouth College Weekly Schedule Diagram is at:

oracle-www.dartmouth.edu/dart/groucho/timetabl.diagram

COURSE TIMES

Course times are indicated for 2 years. Not all courses listed are offered each year.

Check the Dartmouth Timetable of Class Meetings rather than the ORC to confirm the latest information about course meeting times, instructor, etc.

oracle-www.dartmouth.edu/dart/groucho/timetable.main

CANCELLATION POLICY

Any listed course may be cancelled if the enrollment is fewer than 5 students.

Undergraduate Courses by Category

| COURSES RECOMMENDED FOR NON-MAJORS | | |
|------------------------------------|-----------|---|
| | ENG 1.01 | Mathematical Concepts in Engineering |
| | ENG 2 | Integrated Design: Engineering, Architecture, and Building Technology |
| | ENG 3 | Materials: The Substance of Civilization |
| | ENG 4 | Technology of Cyberspace |
| | ENG 5 | Healthcare and Biotechnology in the 21st Century |
| | ENG 6 | Technology and Biosecurity |
| | ENG 7.02 | Climate Change |
| | ENG 7.05 | Contemporary and Historical Perspectives on Medical Imaging |
| | ENG 7.06 | Sustainability Revolution |
| | ENG 8 | Materials in Sports Equipment |
| | ENG 9 | Everyday Technology |
| | ENG 10 | The Science and Engineering of Digital Imaging |
| | ENG 11 | The Way Things Work |
| | ENG 12 | Design Thinking |
| | ENG 13 | Virtual Medicine and Cybercare |
| | ENG 15 | Undergraduate Investigations in Engineering |
| | ENG 15.01 | Senior Design Challenge 1 |
| | ENG 15.02 | Senior Design Challenge 2 |
| | ENG 16 | Biomedical Engineering for Global Health |
| | ENG 18 | System Dynamics in Policy Design and Analysis |
| COURSES FOR MAJORS AND MINORS | | |
| Engineering Sciences Prerequisite | ENG 20 | Introduction to Scientific Computing |
| Common Core Courses | ENG 21 | Introduction to Engineering |
| | ENG 22 | Systems |
| | ENG 23 | Distributed Systems and Fields |
| Distributional Core Courses | ENG 24 | Science of Materials |
| | ENG 25 | Introduction to Thermodynamics |
| | ENG 26 | Control Theory |
| | ENG 27 | Discrete and Probabilistic Systems |
| Gateway Courses | ENG 30 | Biological Physics |
| | ENG 31 | Digital Electronics |
| | ENG 32 | Electronics: Introduction to Linear and Digital Circuits |
| | ENG 33 | Solid Mechanics |
| | ENG 34 | Fluid Mechanics |
| | ENG 35 | Biotechnology and Biochemical Engineering |
| | ENG 36 | Chemical Engineering |
| | ENG 37 | Introduction to Environmental Engineering |
| Introductory Courses | ENG 52 | Introduction to Operations Research |
| | ENG 56 | Introduction to Biomedical Engineering |

continued

Undergraduate Courses by Category continued

| COURSES FOR MAJORS AND MINORS | | |
|-------------------------------|---------|---|
| Upper-Level Courses | ENGS 41 | Sustainability and Natural Resource Management |
| | ENGS 43 | Environmental Transport and Fate |
| | ENGS 44 | Sustainable Design |
| | ENGS 46 | Advanced Hydrology |
| | ENGS 50 | Software Design and Implementation |
| | ENGS 57 | Intermediate Biomedical Engineering |
| | ENGS 58 | Protein Engineering |
| | ENGS 60 | Introduction to Solid-State Electronic Devices |
| | ENGS 61 | Intermediate Electrical Circuits |
| | ENGS 62 | Microprocessors in Engineered Systems |
| | ENGS 64 | Engineering Electromagnetics |
| | ENGS 65 | Engineering Software Design |
| | ENGS 66 | Discrete Mathematics in Computer Science |
| | ENGS 67 | Programming Parallel Systems |
| | ENGS 68 | Introduction to Communication Systems |
| | ENGS 69 | Smartphone Programming |
| | ENGS 71 | Structural Analysis |
| | ENGS 72 | Applied Mechanics: Dynamics |
| | ENGS 73 | Materials Processing and Selection |
| | ENGS 75 | Product Design |
| | ENGS 76 | Machine Engineering |
| | ENGS 84 | Reading Course |
| | ENGS 85 | Special Topics |
| | ENGS 86 | Independent Project |
| | ENGS 87 | Undergraduate Investigations |
| | ENGS 88 | Honors Thesis |
| | ENGS 89 | Engineering Design Methodology and Project Initiation |
| | ENGS 90 | Engineering Design Methodology and Project Completion |
| | ENGS 91 | Numerical Methods in Computation |
| | ENGS 92 | Fourier Transforms and Complex Variables |
| | ENGS 93 | Statistical Methods in Engineering |

Undergraduate Course Descriptions

For the most current information about course offerings and times, see engineering.dartmouth.edu/academics/courses/undergraduate

ENGS 1.01 Mathematical Concepts in Engineering

Offered: 18F, 19F: 2A

This course introduces prospective engineering students to mathematical concepts relevant in engineering while emphasizing the solving of engineering problems rather than mathematical derivations and theory. All topics are driven by engineering applications taken directly from core engineering courses. The course includes hands-on laboratory exercises as well as a thorough introduction to Matlab.

Enrollment is limited to 24 students.

No prerequisite

Instructor: P. Taylor

Dist: TAS

ENGS 2 Integrated Design: Engineering, Architecture, and Building Technology

Offered: 19W, 20W: 12 19X: 2A

An introduction to the integrated design of structures and the evolving role of architects and engineers. The course will investigate the idea that design excellence is very often the result of deep collaboration between engineers, architects, and builders and that it is only in relatively recent history that a distinction between these areas of expertise has existed. The historical, social, and architectural impact of structures will be explored and several structures and their designers will be studied in depth.

Enrollment is limited to 50 students.

No prerequisite

Instructor: Wilson

Dist: TAS

ENGS 3 Materials: The Substance of Civilization

Not offered 2018–2019

With the exception of ideas and emotions, materials are the substance of civilization. From the “Iceman’s” copper ax to indium phosphide gallium arsenide semiconductor lasers, materials have always defined our world. We even name our epochs of time based on the dominant material of the age: Stone Age, Bronze Age, Iron Age and now Silicon Age. In addition to discussing the nature and processing of metals, polymers, ceramics, glass and electronic materials, this course will analyze the dramatic developments in civilization directly resulting from advances in such materials. The text, Stephen Sass’ *The Substance of Civilization*, will be used in the course. Enrollment is limited to 75 students per section.

No prerequisite

Dist: TAS

ENGS 4 Technology of Cyberspace

Offered: 18F: 10A

This course will cover some basic concepts underlying the “information superhighway.” The technologies of high speed networking have stimulated much activity within the federal government, the telecommunications and computer industries, and even social science and popular fiction writing. The technical focus will be on communications technologies, information theory, and the communications requirements of video (standard and ATV), speech (and other audio), text data. Social, economic, and policy issues will be an integral part of the course.

Enrollment is limited to 30 students.

No prerequisite

Instructor: S. Taylor

Dist: TAS

ENGS 5 Healthcare and Biotechnology in the 21st Century

Offered: 19S, 20S: 2A

Technologies that will impact healthcare in the 21st century are explored, including biology, robotics, and information. Biotechnologies are explored that will be used for the treatment of diseases and the regeneration of missing organs and limbs. Robotics will be explored that will replace parts. This will include artificial organs, robots as replacement for human parts, the human genome project, gene therapy, biomaterials, genetic engineering, cloning, transplantation (auto, allo and xeno), limb regeneration, man-machine interfaces, robotics, prosthetic limbs, artificial organs and joints. This section will also cover ethical issues related to the above topics and issues regarding the FDA and the approval of new medical treatments. We will discuss going beyond normal with respect to the senses, muscles and creating wings. Enrollment is limited to 75 students.

No prerequisite

Instructors: Robbie, Rosen

Dist: TAS

ENGS 6 Technology and Biosecurity

Offered: 19S, 20S: 2A

This course will introduce students to the technologies used to combat biological threats to security ranging from pandemic influenza to bioterrorism. In particular, this course will explore the dual role that technology plays in both enhancing and destabilizing security. Specific technologies covered include the use of nanotechnology, synthetic biology, and mass spectrometry. The course considers questions such as: Where can technological solutions have the greatest impact? When can defensive technologies have offensive applications? And, how can we balance the need to regulate potentially dangerous technologies against the need for academic freedom and high tech innovation? Enrollment is limited to 30 students.

No prerequisite

Instructor: Hoyt

Dist: TAS

ENGS 7 First-Year Seminars in Engineering*The following two courses are available only as part of the First-Year Seminar Program.***ENGS 7.02 Climate Change**

Offered: 19W, 20W: 9L

Climate change has occurred naturally and frequently over the course of many time scales in the past. America today is engaged in a discussion of current climate change and its cause, ranging from calls for immediate action to denial. This course explores the published scientific literature on the nature and cause of climate change, potential impacts on us, and the implications for our nation's energy issues. Through readings, class discussion, and individual research, we will explore this complex problem; student writing will synthesize results from the literature to clarify the factual basis for their own understanding. Reading will include a number of published papers and selections from textbooks. Students will be required to actively participate in class by leading class discussions and actively engaging in small group activities. In addition students will write two short papers, develop an annotated bibliography, and write a research paper based on the research completed for the annotated bibliography. Enrollment is limited to 16 students.

Instructor: Albert

Dist: TAS

ENGS 7.05 Contemporary and Historical Perspectives on Medical Imaging

Offered: 19S, 20S: 12

Medical imaging has evolved significantly over the last 100 years and has transformed modern medical practice to the extent that very few clinical decisions are made without relying on information obtained with contemporary imaging modalities. The future of medical imaging may be even more promising as new technologies are being developed to observe the structural, functional, and molecular characteristics of tissues at finer and finer spatial scales. This first-year seminar will review the historical development of modern radiographic imaging and discuss the basic physical principles behind common approaches such as CT, ultrasound, and MRI. Contemporary issues surrounding the use of imaging to screen for disease, the costs to the health care system of routine application of advanced imaging technology, and the benefits of the information provided by medical imaging in terms of evidence-based outcomes assessment will be explored. Students will be required to read, present, and discuss materials in class and write position papers articulating and/or defending particular perspectives on the historical development of medical imaging and its contemporary and/or future uses and benefits. Enrollment is limited to 16 students.

Instructor: Paulsen

Dist: TAS

ENGS 7.06 Sustainability Revolution

Offered: 20S: arrange

Humanity has previously seen two major resource transitions that have had radical impacts on day-to-day life: the Neolithic revolution (from hunting and gathering to agrarian) and the industrial revolution (from agrarian to pre-sustainable industrial). This writing course will consider the hypothesis that the human enterprise now requires a third such resource revolution—the sustainability revolution (from pre-sustainable industrial to sustainable industrial)—and that future generations will judge those of us alive today by how well we responded to this imperative. Topics addressed include past resource revolutions, resource and environmental metrics, energy, food, water, and climate. Writing assignments will include a personal essay, a critique encompassing one or a few sources, and an integrated analysis. Enrollment is limited to 16 students.

Instructor: Lynd

Dist: TAS

ENGS 8 Materials in Sports Equipment

Not offered 2018–2019

Sports equipment uses almost every type of material imaginable, as athletes and designers leverage state-of-the-art materials to maximize human efficiency, performance, comfort and safety. As something most people have some familiarity with, active Dartmouth students in particular, it is an excellent subject for an exploration of material characteristics, selection, design, and failure. This course will introduce materials science concepts in a way that is accessible and useful for the non-major. It will exercise student's critical thinking, quantitative and communication skills. In-class demonstrations will allow students to explore material behavior and differences between materials "hands-on" and possible field trips or lab visits will introduce them to some engineering test methods. Finally, this course will demystify terms used by manufacturers and salespeople, and help students, as athletes and consumers, make informed equipment choices. Enrollment is limited to 30 students.

No prerequisite

Dist: TAS

ENGS 9 Everyday Technology

Offered: 19S, 20S: 11, lab

This course is intended to take the mystery out of the technology that we have grown to depend on in our everyday lives. Both the principles behind and examples of devices utilizing electricity, solid and fluid properties, chemical effects, mechanical attributes and other topics will be discussed. In the associated lab project, students will dissect, analyze, (and possibly revive!) a broken gadget or appliance of their choosing. Enrollment is limited to 50 students.

No prerequisite

Instructor: Davis

Dist: TLA

ENGS 10 The Science and Engineering of Digital Imaging

Not offered 2018–2019

Recent advances in electrical and computer engineering, computer science and applied mathematics have made remarkable digital imaging systems possible. Such systems are affecting everyone today—from eyewitness documentation of social and political events to health care to entertainment to scientific discovery. This course will introduce students to the fundamental concepts underlying a diverse and representative collection of modern digital imaging systems including cell phone cameras, medical imaging systems, space telescopes, computer games and animated movies. Specific attention will be paid to the scientific principles and engineering challenges underlying optics, computer processing chips, image processing software and algorithms, data compression and communication, and digital sensors as well as the basic principles of human vision and cognition. Students will explore and learn the basic science and technology through a combination of in-class lectures and active hands-on experimentation with digital cameras, image processing software and digital video systems. Students will participate in a course-long group project that demonstrates their understanding of and ability to harness these new technologies. Students will be expected to have access to an entry-level digital camera, either standalone or attached to a cell phone or tablet computer. Enrollment is limited to 40 students.

No prerequisite

Dist: TAS

ENGS 11 The Way Things Work: A Visual Introduction to Engineering

Offered: 19W, 20W: 10A

Students will explore and compare engineered solutions to challenges or problems in the world around them. They will sketch and build models to help understand and communicate. After being exposed to some basic engineering principles they will be asked to further investigate specific challenges and possible engineering solutions.

What is the problem or need? What are some possible engineered solutions? What are the pros and cons of the different solutions? How could these solutions be improved? They will communicate their findings visually to the class, to the Thayer community, and beyond. Enrollment is limited to 24 students.

No prerequisite

Instructors: May, Macaulay

Dist: ART

ENGS 12 Design Thinking

Offered: 18F, 19F: 10A

19W, 20W: 10A, 2A

19S, 20S: 10A

A foundation course on the cognitive strategies and methodologies that form the basis of creative design practice. Design thinking applies to innovation across the built-environment, including the design of products, services, interactive technology, environments, and experiences. Topics include design principles, human need-finding, formal methodologies, brainstorming, heuristics, thinking by analogy, scenario building, visual thinking, and study of experienced thinkers. Weekly projects and exercises in a variety of media provide practice and development of students' personal creative abilities. Enrollment is limited to 20 students.

No prerequisite

Instructor: Robbie, Korsunskiy

Dist: TAS

ENGS 13 Virtual Medicine and Cybercare

Offered: 18F: 2A

There is a revolution in technology that is occurring in health care. This new technology will dramatically change how health care is delivered in the future.

This course will cover topics related to the virtual human created from bits. This will include virtual reality, augmented reality and datafusion, computer simulation, advanced 3D and 4D imaging techniques, the operating room of the future, minimally invasive surgery, space medicine, teleoperations, telemedicine and telesurgery, internet 2 and cyber-space, artificial intelligence and intelligent agents applied to medicine, and the national library of medicine virtual human project.

We will also discuss the FDA approval of computer simulators, robotic surgeons, and the ethics of robots doing surgery. In addition we will discuss the medical library of the future, teleconferencing and the use of interactive media in healthcare education. We will also discuss computerized patient records (CPR) and clinical information systems. Enrollment is limited to 48 students.

No prerequisite

Instructor: Rosen

Dist: TAS

ENGS 15 Undergraduate Investigations in Engineering

Offered: all terms: arrange

An original investigation in a phase of science or engineering under the supervision of a member of the staff. Students electing the course will be expected to have a proposal approved by the department chair and to meet weekly with the staff member supervising the investigation. The course is open to undergraduates who are not majoring in engineering. It may be elected only once, or taken as a one-third course credit for each of three consecutive terms. A report describing the details of the investigation must be filed with the department chair and approved at the completion of the course.

Prerequisite: Permission of department chair (a one-page proposal submission is required and must be submitted for approval prior to the end of the term preceding the term in which the course will be taken).

Dist: TAS

ENGS 15.01 Senior Design Challenge I

19W: 10A

The Senior Design Challenge is a two-term course designed to serve as a senior capstone experience for Dartmouth students across all majors. Students in this project-based course will practice human-centered design, developing not only the skills, but also the creative confidence to apply their liberal arts education to make a positive difference in the world beyond Dartmouth. Students will work in interdisciplinary teams on projects that will be determined in partnership with organizations in the Upper Valley. The project topics will be designed to give students some flexibility in determining the specific problem on which to focus, while ensuring client responsiveness and substantial fieldwork opportunities. Enrollment is limited.

No prerequisite

Instructor: Korsunskiy

Dist: TAS

ENGS 15.02 Senior Design Challenge II

19S: 3B

The Senior Design Challenge is a two-term course designed to serve as a senior capstone experience for Dartmouth students across all majors. Students in this project-based course will practice human-centered design, developing not only the skills, but also the creative confidence to apply their liberal arts education to make a positive difference in the world beyond Dartmouth. Students will work in interdisciplinary teams on projects that will be determined in partnership with organizations in the Upper Valley. The project topics will be designed to give students some flexibility in determining the specific problem on which to focus, while ensuring client responsiveness and substantial fieldwork opportunities. Enrollment is limited.

No prerequisite

Instructor: Korsunskiy

Dist: TAS

ENGS 16 Biomedical Engineering for Global Health

Offered: 19W: 2A

The past 20 years have seen an incredible amount of high-tech medical advances, but to what degree have these impacted the health of those living in the developing world? The potential for years of life gained through biomedical technology is tremendous in some of the world's poorest regions, but appropriate design requires an understanding of the clinical, political, and cultural landscape, and a clean-slate approach to developing low-cost, effective tech.

This course offers an exciting opportunity to understand how to design solutions for the most important health challenges of the developing world. Learning goals will be achieved through hands-on experience, including: a laboratory component where we deconstruct, design and build a low-cost medical device, case study discussions on successful global health innovations, and several "teardowns" of common medical devices. Lecturers from Thayer, Tuck School of Business, the Dartmouth Center for Health Care Delivery Science, and Geisel School of Medicine will cover complimentary topics in clinical medicine, healthcare delivery, innovation and medical imaging. A final project will bring everything together by addressing a real health problem with a prototype of a low-cost tech solution. Enrollment is limited to 40 students.

No prerequisite

Instructor: Elliott

Dist: TAS

ENGS 18 System Dynamics in Policy Design and Analysis

Offered: 19W, 20W: 2A

This course introduces systems dynamics, an approach to policy design and analysis based upon feedback principles and computer simulation. The approach is useful for gaining an understanding of the underlying structural causes of problem behavior in social, economic, political, environmental, technological, and biological systems. Goals of this approach are to gain better understanding of such problem behaviors and to design policies aimed at improving them. Lectures and exercises illustrate applications of the approach to real, current problems such as urban decay, resource depletion, environmental pollution, product marketing and distribution, and agricultural planning in an expanding population. The similarity and transferability of underlying feedback characteristics among various applications is emphasized.

No prior engineering or computer science experience is necessary. Enrollment is limited to 30 students.

Prerequisite: MATH 3

Instructor: Peterson

Dist: TAS

ENGS 19 Microchips in Everyday Life

Not offered 2018–2019

This course will be an introductory laboratory/lecture course in which students make microelectronic devices, such as transistors, diodes, resistors and capacitors in the laboratory and understand how they work in lectures. The goal of this course is for each student to obtain hands-on experience in device microfabrication and electronic measurement, as well as to provide an overview over the general trend of lithographic miniaturization and nanotechnology.

No prerequisite

Dist: TLA0

ENGS 20 Introduction to Scientific Computing

(May not be taken under the non-recording option)

Offered: 18F, 19F: 10

19W, 20W: 10

19S, 20S: 11, 12

This course introduces concepts and techniques for creating computational solutions to problems in engineering and science. The essentials of computer programming are developed using the C and Matlab languages, with the goal of enabling the student to use the computer effectively in subsequent courses. Programming topics include problem decomposition, control structures, recursion, arrays and other data structures, file I/O, graphics, and code libraries. Applications will be drawn from numerical solution of ordinary differential equations, root finding, matrix operations, searching and sorting, simulation, and data analysis. Good programming style and computational efficiency are emphasized. Although no previous programming experience is assumed, a significant time commitment is required.

Students planning to pursue the engineering sciences major are advised to take ENGS 20. Students considering the computer science major or majors modified with computer science should take COSC 1 and COSC 10.

Enrollment is limited to 50 students.

Prerequisite: MATH 3 and prior or concurrent enrollment in MATH 8

Instructors: Shepherd (fall, winter), P. Taylor (spring)

Dist: TAS

ENGS 21 Introduction to Engineering

Offered: 18F, 19F: 10A 19W, 20W: 10A 19S, 20S: 10A

The student is introduced to engineering through participation, as a member of a team, in a complete design project. The synthesis of many fields involving the laws of nature, mathematics, economics, management, and communication is required in the project. Engineering principles of analysis, experimentation, and design are applied to a real problem, from initial concept to final recommendations. The project results are evaluated in terms of technical and economic feasibility plus social significance. Lectures are directed toward the problem, and experiments are designed by students as the need develops. Enrollment is limited to 64 students. Priority will be given to sophomores.

Prerequisite: MATH 3 or equivalent

Instructors: Wegst (fall), Collier (winter), May (spring)

Dist: TAS

ENGS 22 Systems

Offered: 18F, 19F: 2, lab 19W, 20W: 9L, lab 19S, 20S: 9L, lab 19X: 10, lab

The student is introduced to the techniques of modeling and analyzing lumped systems of a variety of types, including electrical, mechanical, reacting, fluid, and thermal systems. System input will be related to output through ordinary differential equations, which will be solved by analytical and numerical techniques. Systems concepts such as time constant, natural frequency, and damping factor are introduced. The course includes computer and laboratory exercises to enhance the students' understanding of the principles of lumped systems. Students will develop the ability to write MATLAB code. Enrollment is limited to 50 students.

Prerequisite: MATH 13, PHYS 14, and ENGS 20

Instructors: Farid (fall), Trembly (winter), Stauth (spring), Zhang (summer) Dist: TLA

ENGS 23 Distributed Systems and Fields

Offered: 18F, 19F: 2 19W, 20W: 9L 19S, 20S: 9L

A study of the fundamental properties of distributed systems and their description in terms of scalar and vector fields. After a summary of vector-field theory, the formulation of conservation laws, source laws, and constitutive equations is discussed. Energy and force relations are developed and the nature of potential fields, wave fields, and diffusion fields examined. A survey of elementary transport processes is given. Particular attention is given to the relation between the description of systems in terms of discrete and distributed parameters. Applications are chosen primarily from fluid mechanics, electromagnetic theory, and heat transfer. Includes a set of laboratories. Enrollment is limited to 50 students.

Prerequisite: ENGS 22, or equivalent

Instructors: Sullivan (fall), Hansen (winter), Trembly (spring)

Dist: TAS

ENGS 24 Science of Materials

Offered: 19W, 20W: 10, lab 19S, 20S: 10, lab 19X: 11, lab

An introduction to the structure/property relationships that govern the mechanical, the thermal, and the electrical behavior of solids (ceramics, metals, and polymers). Topics include atomic, crystalline, and amorphous structures; x-ray diffraction; imperfections in crystals; phase diagrams; phase transformations; elastic and plastic deformation; free electron theory and band theory of solids; and electrical conduction in metals and semiconductors. The laboratory consists of an experimental project selected by the student and approved by the instructor. Enrollment is limited to 50 students.

Prerequisite: PHYS 14 and CHEM 5

Instructors: Liu, Levey (winter), Li, Levey (spring), Liu, Cullen (summer)

Dist: TLA

ENGS 25 Introduction to Thermodynamics

Offered: 19S, 20S: 2

19X: 10A

20W: arrange

The fundamental concepts and methods of thermodynamics are developed around the first and second laws. The distinctions among heat, work, and energy are emphasized. Common processes for generating work, heat, refrigeration, or changing the physical or chemical state of materials are analyzed. The use of thermodynamic data and auxiliary functions, such as entropy, enthalpy, and free energy, is integrated into the analysis. The numerous problems show how theoretical energy requirements and the limitations on feasible processes can be estimated. Enrollment is limited to 50 students.

Prerequisite: MATH 13, PHYS 13, ENGS 20 or COSC 1 and COSC 10

Instructors: Lynd (spring), Chen (summer), Ray (winter)

Dist: TAS

ENGS 26 Control Theory

Offered: 18F, 19F: 9L

19S: 9L

The course treats the design of analog, lumped parameter systems for the regulation or control of a plant or process to meet specified criteria of stability, transient response, and frequency response. The basic theory of control system analysis and design is considered from a general point of view. Mathematical models for electrical, mechanical, chemical, and thermal systems are developed. Feedback control system design procedures are established using root-locus and frequency-response methods. Enrollment is limited to 50 students.

Prerequisite: ENGS 22

Instructors: Phan (fall), Ray (spring)

Dist: TAS

ENGS 27 Discrete and Probabilistic Systems

Offered: 18F, 19F: 10

This course is an introduction to probabilistic methods for modeling, analyzing, and designing systems. Mathematical topics include the fundamentals of probability, random variables and common probability distributions, basic queueing theory, and stochastic simulation. Applications, drawn from a variety of engineering settings, may include measurement and noise, information theory and coding, computer networks, diffusion, fatigue and failure, reliability, statistical mechanics, ecology, decision making, and robust design. Enrollment is limited to 50 students.

Prerequisite: MATH 8 and either ENGS 20 or COSC 1 and COSC 10. PHYS 13 or CHEM 5 recommended.

Instructor: Cybenko

Dist: TAS

ENGS 30 Biological Physics

(Identical to PHYS 30)

Offered: 19S: 11

Introduction to the principles of physics and engineering applied to biological problems. Topics include the architecture of biological cells, molecular motion, entropic forces, enzymes and molecular machines, and nerve impulses. Enrollment is limited to 20 students.

Prerequisite: CHEM 5, PHYS 13 and PHYS 14 (or equivalent). PHYS 14 (or equivalent) may be taken concurrently. Students with strong quantitative skills who have taken PHYS 3 and PHYS 4 can enroll with permission of the instructor.

Instructor: Hill

Dist: TAS

ENGS 31 Digital Electronics

(Identical to COSC 56)

Offered: 19S, 20S: 12, lab 19X: 9L, lab

This course teaches classical switching theory including Boolean algebra, logic minimization, algorithmic state machine abstractions, and synchronous system design. This theory is then applied to digital electronic design. Techniques of logic implementation, from Small Scale Integration (SSI) through Application-Specific Integrated Circuits (ASICs), are encountered. There are weekly laboratory exercises for the first part of the course followed by a digital design project in which the student designs and builds a large system of his or her choice. In the process, Computer-Aided Design (CAD) and construction techniques for digital systems are learned. Enrollment is limited to 55 students.

Prerequisite: ENGS 20 or COSC 1 and COSC 10

Instructors: Luke (spring), Hansen (summer)

Dist: TLA

ENGS 32 Electronics: Introduction to Linear and Digital Circuits

(Identical to PHYS 48)

Offered: 19W, 20W: 11, lab

Principles of operation of semiconductor diodes, bipolar and field-effect transistors, and their application in rectifier, amplifier, waveshaping, and logic circuits. Basic active-circuit theory. Introduction to integrated circuits: the operational amplifier and comparator, to include practical considerations for designing circuits with off-the shelf components. Emphasis on breadth of coverage of low-frequency linear and digital networks, as well as on high order passive and active filter design. Laboratory exercises permit "hands-on" experience in the analysis and design of simple electronic circuits. The course is designed for two populations: a) those desiring a single course in basic electronics, and b) those that need the fundamentals necessary for further study of active circuits and systems. Enrollment is limited to 50 students.

Prerequisite: ENGS 22, or equivalent background in basic circuit theory

Instructor: Odame

Dist: TLA

ENGS 33 Solid Mechanics

Offered: 18F, 19F: 11, lab 19W, 20W: 12, lab 19X: 12, lab

After a brief review of the concepts of rigid body statics, the field equations describing the static behavior of deformable elastic solids are developed. The concepts of stress and strain are introduced and utilized in the development. Exact and approximate solutions of the field equations are used in the study of common loading cases, including tension/compression, bending, torsion, pressure, and combinations of these. In the laboratory phase of the course, various methods of experimental solid mechanics are introduced. Some of these methods are used in a project in which the deformation and stress in an actual load system are determined and compared with theoretical predictions. The course includes several computer exercises designed to enhance the student's understanding of the principles of solid mechanics.

Enrollment is limited to 50 students.

Prerequisites: MATH 13 and PHYS 13

Instructors: May (fall), Van Citters (winter), Staff (summer)

Dist: TLA

ENGS 34 Fluid Mechanics

Offered: 19W, 20W: 9L, lab

We interact with fluids every day. From complex systems such as cars, airplanes, and chemical plants, to simple devices like a bike pump, our world is filled with engineering applications that make use of the principles of fluid mechanics. This course surveys the fundamental concepts, phenomena, and methods in fluid mechanics, as well as their application in engineered systems and in nature. Emphasis is placed on the development and use of conservation laws for mass, momentum, and energy, as well as on the empirical knowledge essential to the understanding of many fluid dynamic phenomena. Examples are drawn from mechanical, chemical, civil, environmental, biomedical, and aerospace engineering. Enrollment is limited to 50 students.

Prerequisites: ENGS 23 or equivalent

Instructor: Epps

Dist: TLA

ENGS 35 Biotechnology and Biochemical Engineering

Offered: 18F, 19F: 9L, lab

A consideration of the engineering and scientific basis for using cells or their components in engineered systems. Central topics addressed include kinetics and reactor design for enzyme and cellular systems; fundamentals, techniques, and applications of recombinant DNA technology; and bioseparations. Additional lectures will provide an introduction to metabolic modeling as well as special topics. The course is designed to be accessible to students with both engineering and life-science backgrounds. This course has a graduate section, see ENGS 160. Enrollment is limited to 20 students.

Prerequisite: MATH 3, CHEM 5, BIOL 12 or BIOL 13 or permission

Instructor: Gerngross

Dist: TLA

ENGS 36 Chemical Engineering

Offered: 18F, 19F: 10A

This course will expose students to the fundamental principles of chemical engineering and the application of these principles to a broad range of systems. In the first part of the course, aspects of chemical thermodynamics, reaction kinetics, and transport phenomena will be addressed. These principles will then be applied to a variety of systems including industrial, environmental, and biological examples. Enrollment is limited to 50 students.

Prerequisite: ENGS 22, ENGS 25 and CHEM 5

Instructor: Laser

Dist: TAS

ENGS 37 Introduction to Environmental Engineering

Offered: 18F, 19F: 10

A survey of the sources, measurement techniques, and treatment technologies relating to environmental pollution resulting from the activities of humans. The course will be technology-focused, but will also touch on topics related to the implementation of technology in the real world such as public perception, policy and legislation, and choosing between technological alternatives. Technological and other issues will be addressed relating to water pollution, air pollution, solid wastes, and the fate and transport of pollutants in the environment. Consideration of each area will include general background and key concepts, detailed design examples of importance in the area, and case studies/current topics. The course will include guest lectures. Enrollment is limited to 50 students.

Prerequisite: MATH 3 and CHEM 5, or equivalent, or permission

Instructor: Cushman-Roisin

Dist: TAS

ENGS 41 Sustainability and Natural Resource Management

Offered: 19W, 20W: 12

Natural resources sustain human productivity. Principles of scientific resource management are established, including mathematical model development based on material balances and decision making based on dynamical and stochastic systems. Three generic categories of resource are analyzed: exhaustible, living, and renewable. In the first category, we emphasize the life-cycle of exploitation including exhaustion, exploration and substitution. In the living category, we explore population dynamics under natural and harvested regimes, for fisheries, fowl and forests. The renewable case of water is treated in terms of quantity and quality. Finally, air quality management is considered through the lens of assimilative capacity. Throughout, the intersection of natural processes and economic incentives is explored with dynamical systems theory, computer simulations, and optimization techniques. Case studies illustrate contemporary management problems and practices.

Prerequisite: MATH 23 or ENGS 22, and ENGS 37

Instructor: Cushman-Roisin

Dist: TAS

ENGS 43 Environmental Transport and Fate

Not offered 2018–2019

Introduction to movement and transformation of substances released into the natural environment. Fundamentals of advection, dispersion, and reaction. Aggregation and parameterization of various mixing processes leading to dispersion at larger spatial and temporal scales. Importance of inhomogeneity, anisotropy, and stratification in natural media. Basic principles are illustrated by application to atmospheric, ground water, river, estuarine, coastal, and oceanic pollution problems. Case studies include urban smog, acid rain, Chernobyl fall-out, and stratospheric ozone depletion.

Prerequisite: MATH 13; ENGS 37 or permission

Dist: TAS

ENGS 44 Sustainable Design

Offered: 19S, 20S: 10A

An interdisciplinary introduction to the principles of design for sustainability, with emphasis on the built environment. Through lectures, readings, discussions, and a major design project, students will learn to design buildings and other infrastructure with low to no impact on the environment. Emphasis is on creative thinking, strategies for managing the complexity of the product life-cycle of the infrastructure, and the thorough integration of human and economic aspects in the design. Homework and project activities provide practice in relevant engineering analyses. Enrollment is limited to 25 students.

Prerequisite: ENGS 21 and ENGS 22 or SART 65

Instructor: Cushman-Roisin

Dist: TAS

ENGS 46 Advanced Hydrology

(Identical to EARS 76)

Offered alternate years: 20S: arrange

A survey of advanced methods used to analyze the occurrence and movement of water in the natural environment. The watershed processes controlling the generation of runoff and streamflow are highlighted and used to explore the transport and fate of sediment and contaminants in watersheds. Throughout the course the ideas and concepts are explored through the primary literature, with emphasis given to methods of observation, measurement, data analysis, and prediction.

Prerequisites: MATH 3 and EARS 16 or 33 or BIO 53 or ENGS 43 or permission of instructor

Instructor: Renshaw

Dist: TAS

ENGS 50 Software Design and Implementation

(Identical to COSC 50)

Offered: 18F, 19F: 3B

Techniques for building large, reliable, maintainable, and understandable software systems. Topics include UNIX tools and filters, programming in C, software testing, debugging, and teamwork in software development. Concepts are reinforced through a small number of medium-scale programs and one team programming project.

Prerequisite: COSC 10

Instructor: S. Taylor

Dist: TLA

ENGS 52 Introduction to Operations Research

Offered: 19W, 20W: 10A

Basic concepts of optimization are introduced as aids in systematic decision-making in engineering contexts. Deterministic optimization is developed in the form of linear and integer programming and their extensions. Probabilistic models are introduced in terms of Markov chains, queuing and inventory theory, and stochastic simulation. The course emphasizes the application of these methods to the design, planning, and operation of complex industrial and public systems.

Prerequisite: MATH 8 and MATH 22 or equivalent

Instructor: Santos

Dist: TAS

ENGS 56 Introduction to Biomedical Engineering

Offered: 19S, 20S: 2

This course will survey applications of engineering principles to medical diagnosis/treatment of disease, monitoring/measurement of physiological function, and rehabilitation/replacement of body dysfunction. Case studies will be used to highlight how engineering has advanced medical practice and understanding. Examples will be drawn from bioinstrumentation, bioelectricity, biotransport, biomaterials, and biomechanics. While investigations will focus primarily on the engineering aspects of related topics, issues surrounding patient safety, public policy and regulation, animal experimentation, etc. will be discussed as appropriate.

Prerequisite: ENGS 22, PHYS 13 and PHYS 14 (PHYS 14 may be taken concurrently)

Instructors: Hoopes, Zhang

Dist: TAS

ENGS 57 Intermediate Biomedical Engineering

Offered: 19S: 10

The basic biomedical engineering concepts introduced in ENGS 56 will serve as the foundation for exploring technology in a clinical environment. The specific clinical setting to be explored will be the operating room (OR). This course will introduce a variety of surgical procedures and technologies from an engineering perspective. Areas of focus will include patient monitoring, biophysical tissue properties, general surgical instrumentation, tissue cutting and binding technologies, and optical visualization technologies. In addition, state-of-the-art procedures employing image-guided, minimally invasive, laparoscopic, and robot-assisted surgical technologies will be discussed. The first half of the term will include weekly seminars presented by surgeons describing a particular surgical procedure, the technologies currently used and a surgeon's "wish-list". During the second half of the term, students will undertake a design project aimed at developing a technology that addresses a specific need within the OR. Enrollment is limited to 18 students.

Prerequisite: ENGS 23 and ENGS 56 or equivalent

Instructor: Halter

Dist: TAS

ENGS 58 Introduction to Protein Engineering

Offered: 19W, 20W: 3B

Engineered biomolecules are powering an array of innovations in biotechnology, and this course will familiarize students with key developments in the field. An overview of foundational principles will cover concepts such as the central dogma of biology, atomic scale forces in protein structures, and protein structure-function relationships. Strategies for modifying protein structures will be surveyed, with a particular emphasis on genetic techniques. The development of proteins with practical utility will be highlighted using case studies.

Prerequisites: ENGS 35 or CHEM 41

Instructor: Ackerman

Dist: TAS

ENGS 60 Introduction to Solid-State Electronic Devices

Offered: 19W, 20W: 10A, lab

In this course the physical and operational principles behind important electronic devices such as the solar cell and transistor are introduced. Semiconductor electron and hole concentrations and carrier transport are discussed. Carrier generation and recombination including optical absorption and light emission are covered. P-N junction operation and its application to diodes, solar cells, LEDs, and photodiodes is developed. The field-effect transistor (FET) and bipolar junction transistor (BJT) are then discussed and their terminal operation developed. Application of transistors to bipolar and CMOS analog and digital circuits is introduced. The course is primarily intended for students interested in electronics, including digital, analog, power and energy, both at component and integrated circuit levels. The course may also be useful to students interested in electronic materials, device microfabrication and communications.

Prerequisite: ENGS 23

Instructor: Fossum

Dist: TLA

ENGS 61 Intermediate Electrical Circuits

Offered: 19W, 20W: 11

This course will build on ENGS 32, providing a foundation for transistor- level analog and digital circuit design. The course will start with an introduction to the Semiconductor Industry and how it has dramatically altered the modern way of life, resulting in diverse technologies from the iPhone and Facebook to LED lighting and electric transportation. This will lead into basic semiconductor theory and CMOS device models, two-port linearized models, and finally single- and multi-stage amplifiers with applications motivated by wireless communications and biomedical instrumentation. The second half of the class will focus on digital circuits. Topics will include designing and optimizing complex static CMOS in terms of energy, delay, and area for computational blocks and memory arrays (SRAM, DRAM, and FLASH). The class will have weekly labs and a final project that will utilize modern computer-aided design tools (Cadence). The course will prepare the student for advanced study of highly integrated electrical circuits.

Prerequisite: ENGS 32

Instructor: Stauth

Dist: TLA

ENGS 62 Microprocessors in Engineered Systems

Offered: 19W, 20W: 2A, lab

Microprocessors and microcomputers are central components in an ever-increasing number of consumer, industrial, and scientific products. This course extends the design frame-work developed in ENGS 31 to include these high integration parts. Students are introduced to simple and advanced microcomputers, their supporting peripheral hardware, and the hardware and software tools that aid designers in creating embedded system controllers. Laboratory projects will cover basic microprocessor behavior, bus interfaces, peripheral devices, and digital signal processing. Enrollment is limited to 30 students.

Prerequisite: ENGS 20 and ENGS 31

Instructor: S. Taylor

Dist: TLA

ENGS 64 Engineering Electromagnetics

Offered: 18F: 11

Conceptual development, techniques and engineering applications in electrostatics, magnetostatics and magnetic induction; displacement current and Maxwell's equations; transmission line analysis; propagation, reflection, refraction and dispersion of electromagnetic waves.

Prerequisites: ENGS 23

Instructor: Shubitidze

Dist: TAS

ENGS 65 Engineering Software Design

Offered: 19W, 20W: 3B

As a successor to ENGS 20, this course covers intermediate topics in programming and software design with an emphasis on engineering applications. Students will learn software design principles and basic data structures. Topics covered will include object-oriented design, user interface design, lists, stacks, queues, binary trees, hash tables, and simulation. Students will learn techniques for developing maintainable, extensible, and understandable software.

Prerequisite: ENGS 20 or COSC 1 and COSC 10

Instructor: Santos

Dist: TAS

ENGS 66 Discrete Mathematics in Computer Science

(Identical to COSC 30)

Offered: 18F: arrange 19W: arrange

This course integrates discrete mathematics with algorithms and data structures, using computer science applications to motivate the mathematics. It covers logic and proof techniques, induction, set theory, counting, asymptotics, discrete probability, graphs, and trees. MATH 19 is identical to COSC 30 and may substitute for it in any requirement.

Prerequisite: ENGS 20 or COSC 1 and COSC 10 or advanced placement

Instructor: Staff

Dist: QDS

ENGS 67 Programming Parallel Systems

(Identical to COSC 63)

Offered: 19F: 2A, lab

Multi-core processors are now ubiquitous in most personal computers. These are the fundamental computer-engineering building blocks for high-performance servers, blade farms, and cloud computing. In order to utilize these devices in large systems they must be interconnected through networking and collectively programmed. This hands-on system-engineering course offers students the opportunity to explore problem-solving techniques on a high-performance multi-computer containing quad-core processors. The course involves weekly programming laboratories that teach POSIX thread, UDP and TCP network, and MPI style programming techniques. These techniques are explored in the context of scalable problem solving methods applied to typical problems in science and engineering ranging from client-server sensing and data repositories, to numerical methods, gaming and decision support. All laboratories will be conducted in the C programming language and proficiency in C is required. Enrollment is limited to 30 students.

Prerequisite: ENGS 20 or COSC 50

Instructor: S. Taylor

Dist: TLA

ENGS 68 Introduction to Communication Systems

Offered: 19W, 20W: 2

This course provides an introduction to communication systems. The focus is on the deterministic aspects of analog and digital systems. The student is introduced to modeling and analyzing signals in the time and frequency domains. Modulation techniques are addressed as well as sampling, multiplexing, line coding, and pulse shaping. Recent developments in communication systems are briefly discussed.

Prerequisite: Prior or concurrent enrollment in ENGS 22, ENGS 27 and ENGS 92 strongly recommended

Instructor: Testorf

Dist: TAS

ENGS 69 Smartphone Programming

(Identical to COSC 65, COSC 165)

Offered: 19W: arrange

20S: arrange

This course teaches students how to design, implement, test, debug and publish smartphone applications. Topics include development environment, phone emulator, key programming paradigms, UI design including views and activities, data persistence, messaging and networking, embedded sensors, location based services (e.g., Google Maps), cloud programming, and publishing applications. Concepts are reinforced through a set of weekly programming assignments and group projects. Enrollment limited to 50 students.

Prerequisite: COSC 10

Instructors: Yang (winter), Campbell (spring)

Dist: TAS

ENGS 71 Structural Analysis

Offered: 19S, 20S: 10

An introduction to the behavior of structural systems (including examples of buildings, space structures, and mechanical systems), with an emphasis on modeling and approximating behavior. Classical and computational analysis methods for structural load flow through basic three-dimensional structures; methods of approximating the response of planar structures; methods of determining deformations in planar, statically determinate structure; actions and deformations in statically indeterminate structures, using both flexibility/compatibility methods and stiffness/equilibrium methods (including an introduction to matrix methods). A structural system of choice will be redesigned to improve performance.

Prerequisite: ENGS 20 or COSC 1 and COSC 10 and ENGS 33

Instructor: May

Dist: TAS

ENGS 72 Applied Mechanics: Dynamics

Offered: 18F, 19F: 9L

The fundamentals of dynamics with emphasis on their application to engineering problems. Newtonian mechanics including kinematics and kinetics of particles and rigid bodies, work, energy, impulse, and momentum. Intermediate topics will include Lagrange's equations, energy methods, Euler's equations, rigid body dynamics, and the theory of small oscillations.

Prerequisite: ENGS 22

Instructor: Van Citters

Dist: TAS

ENGS 73 Materials Processing and Selection

Offered: 19S, 20S: 10A, lab

In this course the basic concepts of materials science introduced in ENGS 24 are applied to a variety of materials problems and processes. The course will treat processes and principles relevant to both mechanical and electrical engineering applications. Topics include solidification and crystal growth, joining and bonding techniques, deformation processing, surface coatings and thin film deposition, polymer processing, composite materials, magnetic and dielectric materials, powder metallurgy and ceramics processing, materials selection, failure processes, and quality control. The course will involve laboratory exercises and field trips to local industry. Materials applications will be considered on a case study basis, including aerospace and automotive structures, consumer goods, and high performance sports equipment, electric components, VLSI circuit fabrication and packaging.

Prerequisite: ENGS 24 and ENGS 33 or equivalent

Instructor: Wegst

Dist: TLA

ENGS 75 Product Design

(Can be used for AB course count and Engineering Sciences major elective, but may not be used to satisfy BE requirements other than design credit.)

Offered: 20W: 2A

A laboratory course on human-centered product design. A series of design projects form the vehicle for exploring creative strategies for optimizing product design for human use. The course focus includes need-finding, concept development, iterative modeling, prototyping and testing. The goal is synthesis of technical requirements with aesthetic and human concerns. Includes presentations by visiting professional designers. Enrollment is limited to 20 students.

Prerequisite: ENGS 21 or ENGS 89

Instructors: Faludi

Dist: TAS

ENGS 76 Machine Engineering

Offered: 18F, 19F: 10A

An introduction to the analysis and synthesis of mechanical components and systems. Lecture topics focus on design and analysis of mechanical components subject to static and fatigue loading conditions, deformation, and buckling. Power transmission shafting, bearings, and gears will be studied in detail. A survey of design requirements for other components—springs, screws, belts, clutches, brakes, roller chains, and welded and riveted connections—will be provided. The class includes laboratory sessions for developing practical skills in design fabrication. A term project emphasizes the synthesis of a working machine to complete a specified task. The project involves the design or selection of components studied, and includes fabrication and demonstration of the machine. Solid modeling software is used as a design tool. Enrollment is limited to 25 students.

Prerequisite: ENGS 21, ENGS 33, and proficiency with solid modeling software

Instructor: Faludi

Dist: TAS

ENGS 84 Reading Course

Offered: all terms: arrange

Advanced undergraduates occasionally arrange with a Thayer School faculty member a reading course in a subject not occurring in the regularly scheduled curriculum. This course can only be elected once and either ENGS 84 or 85 may be used toward the Engineering Sciences major, but not both.

Prerequisite: Permission of the department chair. (Proposed courses should include a full syllabus, resources and student evaluation methods and must be submitted for approval prior to the end of the term preceding the term in which the course will be taken.)

ENGS 85 Special Topics

Offered: all terms: arrange

From time to time a section of ENGS 85 may be offered in order to provide an advanced course in a topic which would not otherwise appear in the curriculum. This course can only be elected once and either ENGS 84 or 85 may be used toward the Engineering Sciences major, but not both.

Prerequisite: Permission of the department chair

ENGS 86 Independent Project

Offered: all terms: arrange

An individual research or design project carried out under the supervision of a Thayer School faculty member. Students electing this course will be expected to carry out preliminary reading during the preceding term. This course may be taken in one term, or as a one-third course credit for each of three consecutive terms. A major written report and oral presentation will be submitted at the completion of the course. ENGS 86 may be counted as an elective in the major if ENGS 89 is taken as the culminating experience. Only one of either ENGS 86 or 88 may be used in satisfaction of the combined AB major and BE degree requirements.

Prerequisite: Senior standing in the Engineering Sciences major or Bachelor of Engineering standing and permission of the department chair is required. (One-page proposal submission required and must be submitted for approval prior to the end of the term preceding the term in which the course will be taken.)

ENGS 87 Undergraduate Investigations

(May not be used to satisfy any AB major or BE degree requirements)

Offered: all terms: arrange

An original investigation in a phase of science or engineering under the supervision of a Thayer School faculty member. Students electing the course will be expected to carry out preliminary reading during the preceding term and to meet weekly with the staff member supervising the investigation. The course is open to qualified undergraduates with the consent of the department chair, and it may be elected more than once, or taken as a one-third course credit for each of three consecutive terms. A report describing the details of the investigation must be filed with the department chair and approved at the completion of the course.

Prerequisite: Permission of the department chair. (One-page proposal submission required and must be submitted for approval prior to the end of the term preceding the term in which the course will be taken.)

ENGS 88 Honors Thesis

(Can be counted as an elective in the Engineering Sciences major if ENGS 89 is taken as the culminating experience)

Offered: all terms: arrange

Honors version of ENGS 86. A course normally elected by honors students in one term of the senior year. The student will conduct a creative investigation suitable to the major subject under the supervision and guidance of a Thayer School faculty member. Students electing this course will be expected to begin the project work at least one term prior to electing ENGS 88 and may choose to conduct the preliminary investigation under ENGS 87. A major written report and oral presentation will be submitted at the completion of the course. Only one of either ENGS 86 or 88 may be used in satisfaction of the combined AB major and BE degree requirements.

Prerequisite: Permission of the chair of the Honors program

ENGS 89 Engineering Design Methodology and Project Initiation

Offered: 18F, 19F: 2A

This course explores elements of the engineering design process as a means of enhancing student ability in problem definition; development and evaluation of creative alternatives, application and methods of technical and economic analysis, identification and application of ethical and legal constraints, and effective presentation of technical information. Design projects are developed from specifications submitted by industry and other organizations and are pursued over the course of two quarters as a team project, 89/90. Written and oral proposal and progress report are required for the design project during the term. A project advisor is required for each design team to serve as consultant to the team's efforts. ENGS 89, is the first unit of a two-term course sequence 89/90 that must be taken consecutively.

Prerequisite: Prior to enrollment in ENGS 89, at least six engineering courses must be completed. These include ENGS 21 plus five additional courses numbered 22 to 76 (excluding 75) and 91 and above.

Instructors: Halter, Ray

ENGS 90 Engineering Design Methodology and Project Completion

Offered: 19W, 20W: arrange

This course is the second unit in the two-course, team engineering design sequence 89/90. The objective of the course is to develop the student's professional abilities by providing a realistic project experience in engineering analysis, design, and development. Students continue with the design teams formed in ENGS 89 to complete their projects. Design teams are responsible for all aspects of their respective projects, which involve science, innovation, analysis, experimentation, economic decisions and business operations, planning of projects, patents, and relationships with clients. Mid-term and final oral presentations and written reports are required. A faculty member is assigned to each design team to serve as consultant to the team's efforts.

Prerequisite: ENGS 89

Instructors: Halter, Ray

ENGS 91 Numerical Methods in Computation

(Identical to COSC 71)

(Can be used to satisfy graduate degree requirements)

Offered: 18F, 19F: 12

A study and analysis of important numerical and computational methods for solving engineering and scientific problems. The course will include methods for solving linear and nonlinear equations, doing polynomial interpolation, evaluating integrals, solving ordinary differential equations, and determining eigenvalues and eigenvectors of matrices. The student will be required to write and run computer programs.

*Prerequisite: ENGS 20 or COSC 1 and COSC 10; ENGS 22 or MATH 23,
or equivalent*

Instructor: Shepherd

Dist: QDS

ENGS 92 Fourier Transforms and Complex Variables

(Identical to PHYS 70)

(Can be used to satisfy graduate degree requirements)

Offered: 18F, 19F: 2

Survey of a number of mathematical methods of importance in Engineering and Physics with particular emphasis on the Fourier transform as a tool for modeling and analysis. Orthogonal function expansions, Fourier series, discrete and continuous Fourier transforms, generalized functions and sampling theory, complex functions and complex integration, Laplace, Z, and Hilbert transforms. Computational Fourier analysis. Applications to linear systems, waves, and signal processing.

Prerequisite: MATH 46 or ENGS 22 and ENGS 23 or the equivalent

Instructor: Testorf

Dist: QDS

ENGS 93 Statistical Methods in Engineering

(Can be used to satisfy graduate degree requirements)

Offered: 18F, 19F: 11

Offered: 19W, 20W: 3B, T-Th 12:15-2:05

The application of statistical techniques and concepts to maximize the amount and quality of information resulting from experiments. After a brief introductory summary of fundamental concepts in probability and statistics, topics considered will include probability distributions, sampling distributions, estimation and confidence intervals for parameters of statistical distributions, hypothesis testing, design and analysis of variance for single and multiple-factor experiments, regression analysis, estimation and confidence intervals for parameters of non-statistical models, and statistical quality control.

Prerequisite: MATH 13 or equivalent

Instructors: Lasky (fall), Vaze (winter)

Dist: QDS

Prerequisite Courses for Engineering Sciences

Course offerings for all Dartmouth departments are accessed from:
dartmouth.edu/~reg

CHEMISTRY

CHEM 5-6 General Chemistry

Offered: 5. 18F: 10, lab 19W: 9, 10, lab

Offered: 6. 18F: 9, lab 19S: 9, 10, lab

An introduction to the fundamental principles of chemistry, including chemical stoichiometry; the properties of gases, liquids, and solids; solutions; chemical equilibria; atomic and molecular structure; an introduction to thermodynamics; reaction kinetics; and a discussion of the chemical properties of selected elements.

The laboratory work emphasizes physical-chemical measurements, quantitative analysis, and synthesis.

An outline of topics for review of secondary school background in preparation for college general chemistry is available from the Department of Chemistry.

Prerequisites: MATH 3 (or MATH 1 and 2); to take MATH 2 or 3 concurrently with CHEM 5, consult with the department chair; CHEM 5 is a prerequisite for CHEM 6

Dist: SLA

CHEM 10 Honors First-Year General Chemistry

Offered: 18F: 10; lab

CHEM 10 is a general chemistry course for students who have a strong background in chemistry and mathematics and who may have an interest in majoring in the sciences. The course will cover selected general chemistry topics important for higher-level chemistry courses. These include thermodynamics, reaction kinetics, quantum mechanics, and bonding. Laboratory work will emphasize physico-chemical measurements and quantitative analysis.

CHEM 10 is open only to first-year students and enrollment is limited. Admission is by satisfactory performance on a general chemistry proficiency test given during Orientation. Adequate mathematics preparation, equivalent to MATH 3, is also required. CHEM 10 is offered in the fall term and is the prerequisite equivalent to CHEM 5/6. Students who successfully complete CHEM 10 will also be granted credit for CHEM 5, if they have not already been granted such credit.

Prerequisite: MATH 3 or equivalent; satisfactory performance on the general chemistry proficiency test

Supplemental course fee required

Dist: SLA

COMPUTER SCIENCE

COSC 1 Introduction to Programming and Computation

Offered: 18F, 19W, 19S

This course introduces computational concepts that are fundamental to computer science and are useful for the sciences, social sciences, engineering, and digital arts. Students will write their own interactive programs to analyze data, process text, draw graphics, manipulate images, and simulate physical systems. Problem decomposition, program efficiency, and good programming style are emphasized throughout the course. No prior programming experience is assumed.

Dist: TAS

COSC 10 Problem Solving via Object-Oriented Programming

Offered: 18F, 19W, 20S

Motivated by problems that arise in a variety of disciplines, this course examines concepts and develops skills in solving computational problems. Topics covered include abstraction (how to hide details), modularity (how to decompose problems), data structures (how to efficiently organize data), and algorithms (procedures for solving problems). Laboratory assignments are implemented using object-oriented programming techniques.

Prerequisite: COSC 1, ENGS 20, or placement through the Advanced Placement exam or the local placement exam

Dist: TLA

MATHEMATICS

MATH 3 Introduction to Calculus

Offered: 18F: 9, 10, 11, 12, 2 19W: 11, 12, 2

This course is the basic introduction to calculus. Students planning to specialize in mathematics, computer science, chemistry, physics, or engineering should elect this course in the fall term. Others may elect it in the winter.

A study of polynomials and rational functions leads to the introduction of the basic ideas of differential and integral calculus. The course also introduces exponential, logarithmic, and trigonometric functions. The emphasis throughout is on fundamental ideas and problem solving.

MATH 3 is open to all students who have had intermediate algebra and plane geometry. No knowledge of trigonometry is required. The lectures are supplemented by problem sessions.

Dist: QDS

MATH 8 Calculus of Functions of One and Several Variables

Offered: 18F: 10, 11, 12 19W: 11, 2 19S: 10, 11

This course is a sequel to MATH 3 and is appropriate for students who have successfully completed an AB calculus curriculum in secondary school. Roughly half of the course is devoted to topics in one-variable calculus: techniques of integrations, areas, volumes, trigonometric integrals and substitutions, numerical integration, sequences, and series including Taylor series.

The second half of the course generally studies scalar valued functions of several variables. It begins with the study of vector geometry, equations of lines and planes, and space curves (velocity, acceleration, arclength). The rest of the course is devoted to studying different calculus of functions of several variables. Topics include limits and continuity, partial derivatives, tangent planes and differentials, the Chain Rule, directional derivatives and applications, and optimization problems including the use of Lagrange multipliers.

Prerequisite: MATH 3 or equivalent

Dist: QDS

MATH 11 Multivariable Calculus for Two-Term Advanced Placement First-Year Students

Offered: 18F: 10, 11, 12, 2

This course can be viewed as equivalent to MATH 13, but is designed especially for first-year students who have successfully completed a BC calculus curriculum in secondary school. In particular, as part of its syllabus it includes most of the multi-variable calculus material present in MATH 8.

Topics include vector geometry, equations of lines and planes, and space curves (velocity, acceleration, arclength), limits and continuity, partial derivatives, tangent planes and differentials, the Chain Rule, directional derivatives and applications, and optimization problems. It continues with multiple integration, vector fields, line integrals, and finishes with a study of Green's and Stokes' theorem.

Dist: QDS

MATH 13 Calculus of Vector-Valued Functions

Offered: 18F: 11 19W: 10, 11, 2

19S: 10, 12

This course is a sequel to MATH 8 and provides an introduction to calculus of vector-valued functions. Topics include differentiation and integration of parametrically defined functions with interpretations of velocity, acceleration, arclength and curvature. Other topics include iterated, double, triple and surface integrals including change of coordinates. The remainder of the course is devoted to vector fields, line integrals, Green's theorem, curl and divergence, and Stokes' theorem.

Prerequisite: MATH 8 or equivalent.

Note: First-year students who have received 2 terms on the BC exam generally should take MATH 11 instead. On the other hand, if students have had substantial exposure to multi-variable techniques, they are encouraged to take a placement exam during orientation week to determine if placement into MATH 13 is more appropriate.

Dist: QDS

MATH 22 Linear Algebra with Applications

Offered: 18F: 12, 2

19S: 10, 11, 12, 2

19X: 10, 11

This course presents the fundamental concepts and applications of linear algebra with emphasis on Euclidean space. Significant goals of the course are that the student develop the ability to perform meaningful computations and to write accurate proofs. Topics include bases, subspaces, dimension, determinants, characteristic polynomials, eigenvalues, eigenvectors, and especially matrix representations of linear transformations and change of basis. Applications may be drawn from areas such as optimization, statistics, biology, physics, and signal processing.

Students who plan to take either Mathematics 63 or Mathematics 71 are strongly encouraged to take Mathematics 24.

Prerequisite: MATH 8

Dist: QDS

MATH 23 Differential Equations

Offered: 18F: 2

19W: 12, 2

19S: 11, 12

This course is a survey of important types of differential equations, both linear and nonlinear. Topics include the study of systems of ordinary differential equations using eigenvectors and eigenvalues, numerical solutions of first and second order equations and of systems, and the solution of elementary partial differential equations using Fourier series.

Prerequisite: MATH 13

Dist: QDS

PHYSICS

PHYS 13 Introductory Physics I

Offered: 18F: 10, 11 lab 19W: 10A (includes lab), 11 lab

The fundamental laws of mechanics. Reference frames. Harmonic and gravitational motion. Waves in solids and fluids. Thermodynamics and kinetic theory. PHYS 13, 14, and 19 are designed as a three-term sequence for students majoring in a physical science.

Prerequisites: MATH 3 and MATH 8; MATH 8 may be taken concurrently

Dist: SLA

PHYS 14 Introductory Physics II

Offered: 19W: 10 lab 19S: 10, 11 lab

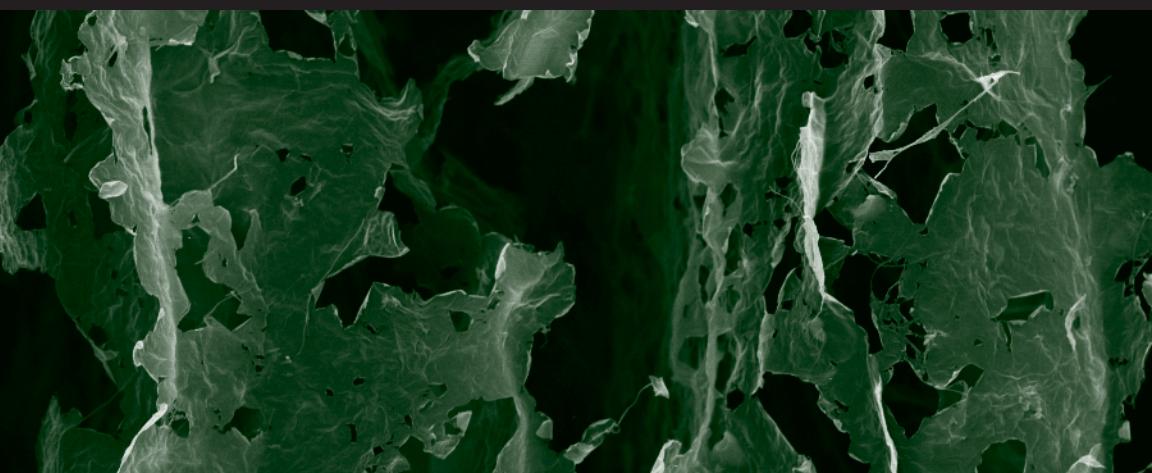
The fundamental laws of electricity and magnetism, Maxwell's equations, waves, electrical and magnetic properties of bulk matter, circuit theory, and optics.

Supplemental course fee required.

Prerequisites: PHYS 13 and MATH 8

Dist: SLA

Graduate Courses



| | |
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| Graduate Courses by Topic | 109 |
| Graduate Course Descriptions | 112 |
| Management Courses (Tuck School of Business) | 143 |

Reduced graphene oxide sheets and carbon nanotubes after neutron irradiation tests.
Imaged by scanning electron microscope by PhD candidate Danielle Castley,
working in Professor Ulrike Wegst's lab.

Graduate Courses

engineering.dartmouth.edu/academics/courses/graduate

Undergraduate engineering science majors may take graduate courses for which they are qualified. Not all graduate courses, however, can be used to satisfy AB and/or Engineering Sciences major requirements.

ENGS Engineering Sciences courses can be used for credit toward the AB degree and to satisfy requirements for the Engineering Sciences major.

ENGG Engineering courses can be used for credit toward the AB degree but do not satisfy requirements for the Engineering Sciences major.

ENGM Engineering Management courses satisfy requirements for the MEM degree. They do not satisfy degree requirements for the Engineering Sciences major.

COURSE NUMBERS

100-199 Courses with engineering prerequisites numbered below 100

200-299 Courses with engineering prerequisites numbered below 200

300-399 Courses with engineering prerequisites numbered below 300

TERM OFFERED

F Fall

W Winter

S Spring

X Summer

CLASS TIMES

The number or number-letter combination that follows the term abbreviation is explained in the timetable below. The x-period is a period of time set aside for instructors to use as needed. For some courses, the x-period is an additional class session.

| CLASS TIMES | | X-PERIOD | |
|-------------|-------------------------------|----------|------------|
| 8 | MTuThF 7:45–8:35 | W | 7:45–8:35 |
| 9S | MTuThF 9:05–9:55 | W | 9:05–9:55 |
| 9L | MWF 8:50–9:55 | Th | 9:05–9:55 |
| 10 | MWF 10:10–11:15 | Th | 12:15–1:05 |
| 10A | TuTh 10:10–12:00 | W | 3:30–4:20 |
| 11 | MWF 11:30–12:35 | Tu | 12:15–1:05 |
| 12 | MWF 12:50–1:55 | Tu | 1:20–2:10 |
| 2 | MWF 2:10–3:15 | Th | 1:20–2:10 |
| 2A | TuTh 2:25–4:15 | W | 4:35–5:25 |
| 3A | MTh M 3:30–5:20, Th 4:30–6:20 | M | 5:35–6:25 |
| 3B | TuTh 4:30–6:20 | M | 5:35–6:25 |
| 6A | MW 6:30–8:20 | | |
| 6B | W 6:30–9:30 | | |

The Dartmouth College Weekly Schedule Diagram is at:

oracle-www.dartmouth.edu/dart/groucho/timetabl.diagram

COURSE TIMES

Course times are indicated for 2 years. Not all courses listed are offered each year.

CANCELLATION POLICY

Any listed course may be cancelled if the enrollment is fewer than 5 students.

Graduate Courses by Topic

| | | |
|----------------------------|----------|---|
| Applied Mathematics | ENGS 91 | Numerical Methods in Computation |
| | ENGS 92 | Fourier Transforms and Complex Variables |
| | ENGS 93 | Statistical Methods in Engineering |
| | ENGS 100 | Methods in Applied Mathematics I |
| | ENGG 103 | Operations Research |
| | ENGS 105 | Computational Methods for Partial Differential Equations I |
| | ENGS 106 | Numerical Linear Algebra |
| | ENGS 107 | Bayesian Statistical Modeling and Computation |
| | ENGS 108 | Applied Machine Learning |
| | ENGS 200 | Methods in Applied Mathematics II |
| | ENGS 202 | Nonlinear Systems |
| | ENGS 205 | Computational Methods for Partial Differential Equations II |
| | ENGG 309 | Topics in Computational Science |

| | | |
|-------------------------------|----------|--|
| Engineering Management | ENGG 176 | Design for Manufacturing |
| | ENGG 177 | Decision Making Under Risk and Uncertainty |
| | ENGM 178 | Technology Assessment |
| | ENGM 179 | Financial and Managerial Accounting |
| | ENGM 180 | Corporate Finance |
| | ENGM 181 | Marketing |
| | ENGM 182 | Data Analytics |
| | ENGM 183 | Operations Management |
| | ENGM 184 | Introduction to Optimization Methods |
| | ENGM 185 | Topics in Manufacturing Design and Processes |
| | ENGM 186 | Technology Project Management |
| | ENGM 188 | Law for Technology and Entrepreneurship |
| | ENGM 189 | Medical Device Development (.5 credit) |
| | ENGM 190 | Platform Design, Management, and Strategy |
| | ENGM 387 | MEM Professional Skills |
| | ENGG 390 | MEM Project |

continued

Graduate Courses by Topic *continued*

| | | |
|-----------------------------------|----------|---|
| Biological & Chemical Engineering | ENGS 157 | Chemical Process Design |
| | ENGS 158 | Chemical Kinetics and Reactors |
| | ENGS 160 | Biotechnology and Biochemical Engineering |
| | ENGS 161 | Metabolic Engineering |
| | ENGS 162 | Basic Biological Circuit Engineering |
| | ENGS 163 | Advanced Protein Engineering |
| | ENGS 260 | Advances in Biotechnology |
| | ENGS 261 | Biomass Energy Systems |
| | ENGS 262 | Advanced Biological Circuit Engineering |
| Biomedical Engineering | ENGS 159 | Molecular Sensors and Nanodevices Biomedical Engineering |
| | ENGS 164 | Medical Diagnostics and Monitoring |
| | ENGS 165 | Biomaterials |
| | ENGG 166 | Quantitative Human Physiology |
| | ENGS 167 | Medical Imaging |
| | ENGG 168 | Biomedical Radiation Transport |
| | ENGS 169 | Intermediate Biomedical Engineering |
| | ENGS 170 | Neuroengineering |
| | ENGG 365 | Advanced Biomaterials |
| | ENGG 367 | Heat Transfer in Hyperthermia |
| Electrical & Computer Engineering | ENGS 110 | Signal Processing |
| | ENGS 111 | Digital Image Processing |
| | ENGS 112 | Modern Information Technologies |
| | ENGS 114 | Networked Multi-Agent Systems |
| | ENGS 115 | Parallel Computing |
| | ENGS 116 | Computer Engineering: Computer Architecture |
| | ENGS 120 | Electromagnetic Waves: Analytical and Modeling Approaches |
| | ENGG 122 | Advanced Topics in Semiconductor Devices |
| | ENGS 123 | Optics |
| | ENGS 124 | Optical Devices and Systems |
| | ENGS 125 | Power Electronics and Electromechanical Energy Conversion |
| | ENGS 126 | Analog Integrated Circuit Design |
| | ENGS 128 | Advanced Digital System Design |
| | ENGS 129 | Biomedical Circuits and Systems |
| | ENGG 210 | Spectral Analysis |
| | ENGG 212 | Communications Theory |
| | ENGS 220 | Electromagnetic Wave Theory |
| | ENGG 310 | Advanced Topics in Signals and Systems |
| | ENGG 312 | Topics in Statistical Communication Theory |
| | ENGG 317 | Topics in Digital Computer Design |
| | ENGG 324 | Microstrip Lines and Circuits |

continued

Graduate Courses by Topic *continued*

| | | |
|---|----------|--|
| Energy Engineering | ENGS 155 | Intermediate Thermodynamics |
| | ENGS 156 | Heat, Mass, and Momentum Transfer |
| | ENGS 171 | Industrial Ecology |
| | ENGS 172 | Climate Change and Engineering |
| | ENGG 173 | Energy Utilization |
| | ENGG 174 | Energy Conversion |
| | ENGS 175 | Energy Systems |
| Materials Science & Engineering | ENGS 130 | Mechanical Behavior of Materials |
| | ENGS 131 | Science of Solid State Materials |
| | ENGS 132 | Thermodynamics and Kinetics in Condensed Phases |
| | ENGS 133 | Methods of Materials Characterization |
| | ENGS 134 | Nanotechnology |
| | ENGS 135 | Thin Films and Microfabrication Technology |
| | ENGG 138 | Corrosion and Degradation of Materials |
| | ENGG 230 | Fatigue and Fracture |
| | ENGG 332 | Topics in Plastic Flow and Fracture of Solids |
| | ENGG 339 | Advanced Electron Microscopy |
| Mechanical & Systems Engineering | ENGS 142 | Intermediate Solid Mechanics |
| | ENGS 145 | Modern Control Theory |
| | ENGS 146 | Computer-Aided Mechanical Engineering Design |
| | ENGS 147 | Mechatronics |
| | ENGG 148 | Structural Mechanics |
| | ENGG 149 | Introduction to Systems Identification |
| | ENGS 150 | Intermediate Fluid Mechanics |
| | ENGS 151 | Environmental Fluid Mechanics |
| | ENGS 152 | Magnetohydrodynamics |
| | ENGS 153 | Computational Plasma Dynamics |
| | ENGS 154 | Aircraft Design |
| | ENGG 240 | Kinematics and Dynamics of Machinery |
| | ENGS 250 | Turbulence in Fluids |
| | | |
| | | |
| MS & PhD Research Courses | ENGG 296 | Graduate Research (1 credit) |
| | ENGG 297 | Graduate Research (2 credits) |
| | ENGG 298 | Graduate Research (3 credits) |
| Individual Course, Seminars & Workshops | ENGG 192 | Independent or Group Study in Engineering Sciences |
| | ENGG 194 | PhD Oral Qualifier |
| | ENGG 195 | Seminar on Science, Technology, and Society |
| | ENGG 197 | PhD Professional Workshops |
| | ENGG 198 | Research-In-Progress Workshops |
| | ENGG 199 | Special Topics in Engineering Sciences |
| | ENGG 299 | Advanced Special Topics in Engineering Sciences |
| PhD Innovation Program | ENGG 300 | Enterprise Experience Project |
| | ENGG 321 | Introduction to Innovation |
| | ENGG 325 | Introduction to Surgical Innovation |

Graduate Course Descriptions

For the most current information about course offerings and times, see
engineering.dartmouth.edu/academics/courses/graduate

ENGS 91 Numerical Methods in Computation

(Identical to COSC 71)

Offered: 18F, 19F: 12

A study and analysis of important numerical and computational methods for solving engineering and scientific problems. The course will include methods for solving linear and nonlinear equations, doing polynomial interpolation, evaluating integrals, solving ordinary differential equations, and determining eigenvalues and eigenvectors of matrices. The student will be required to write and run computer programs.

*Prerequisite: ENGS 20 or COSC 1 and COSC 10; ENGS 22 or MATH 23,
or equivalent*

Instructor: Shepherd

Dist: QDS

ENGS 92 Fourier Transforms and Complex Variables

(Identical to PHYS 70)

Offered: 18F, 19F: 2

Survey of a number of mathematical methods of importance in Engineering and Physics with particular emphasis on the Fourier transform as a tool for modeling and analysis. Orthogonal function expansions, Fourier series, discrete and continuous Fourier transforms, generalized functions and sampling theory, complex functions and complex integration, Laplace, Z, and Hilbert transforms. Computational Fourier analysis. Applications to linear systems, waves, and signal processing.

Prerequisite: MATH 46 or ENGS 22 and ENGS 23 or the equivalent

Instructor: Testorf

Dist: QDS

ENGS 93 Statistical Methods in Engineering

Offered: 18F, 19F: 11

Offered: 19W, 20W: 3B, T-Th 12:15-2:05

The application of statistical techniques and concepts to maximize the amount and quality of information resulting from experiments. After a brief introductory summary of fundamental concepts in probability and statistics, topics considered will include probability distributions, sampling distributions, estimation and confidence intervals for parameters of statistical distributions, hypothesis testing, design and analysis of variance for single and multiple-factor experiments, regression analysis, estimation and confidence intervals for parameters of non-statistical models, and statistical quality control.

Prerequisite: MATH 13 or equivalent

Instructors: Lasky (fall), Vaze (winter)

Dist: QDS

ENGS 100 Methods in Applied Mathematics I

(Students are encouraged to enroll in PHYS 100 Mathematical Methods for Physicists – Offered 18F: 11)

Not offered 2018–2019

Concepts and methods used in the treatment of linear equations with emphasis on matrix operations, differential equations, and eigenvalue problems will be developed following a brief review of analytic function theory. Topics include the Fourier integral, finite and infinite dimensional vector spaces, boundary value problems, eigenfunction expansions, Green's functions, transform techniques for partial differential equations, and series solution of ordinary differential equations. Properties and uses of orthogonal polynomials and special functions such as the hypergeometric, Bessel, Legendre, and gamma functions are included. Applications in engineering and physics are emphasized.

Prerequisite: ENGS 92 or MATH 33 or MATH 43, with permission of instructor, or the equivalent

ENGG 103 Operations Research

Offered: 18F, 19F: 3B

This course provides an overview of a broad range of deterministic and probabilistic operations research models with a focus on engineering applications. Emphasis is on developing strong formulations, understanding key solution concepts, developing efficient algorithms, and grasping the advantages and limitations of each approach. After a brief overview of linear and discrete optimization models, the course covers four main types of techniques: network models, queuing theory, discrete events simulation and game theoretic analysis. Various network models and the corresponding solution algorithms are discussed. Key results and applications of queuing models are presented. Uncertainty associated with real-world modeling is captured through simulation techniques with specific emphasis on discrete events simulation. Equilibrium modeling concepts for strategic form games and extensive form games are introduced as extensions of the core optimization concepts. Application examples are drawn from aerospace, biomedical, civil, computer, electrical, industrial, mechanical, and systems engineering.

Prerequisite: ENGS 93 or equivalent

Instructor: Vaze

ENGS 104 Optimization Methods for Engineering Applications

Not offered 2018–2019

An introduction to various methods of optimization and their uses in modern engineering. Students will learn to formulate and analyze optimization problems and apply optimization techniques in addition to learning the basic mathematical principles on which these techniques are based. Topic coverage includes linear programming, nonlinear programming, dynamic programming, combinatorial optimization and Monte Carlo methods.

Prerequisite: MATH 22 and ENGS 27 or equivalents, or permission of instructor

Instructor: Cybenko

ENGS 105 Computational Methods for Partial Differential Equations

Offered: 20W: 2A

This course concentrates on the numerical solution of partial differential equations commonly encountered in Engineering Sciences. Finite difference and finite element methods are used to solve problems in heat flow, wave propagation, vibrations, fluid mechanics, hydrology, and solid mechanics. The course materials emphasize the systematic generation of numerical methods for elliptic, parabolic, and hyperbolic problems, and the analysis of their stability, accuracy, and convergence properties. Weekly computer exercises will be required to illustrate the concepts discussed in class.

Prerequisite: MATH 23 and ENGS 91 (COSC 71), or equivalents

Instructor: Paulsen

ENGS 106 Numerical Linear Algebra

(Identical to COSC 271)

Not offered 2018–2019

The course examines, in the context of modern computational practice, algorithms for solving linear systems $Ax = b$ and $Ax = \lambda x$. Matrix decomposition algorithms, matrix inversion, and eigenvector expansions are studied. Algorithms for special matrix classes are featured, including symmetric positive definite matrices, banded matrices, and sparse matrices. Error analysis and complexity analysis of the algorithms are covered. The algorithms are implemented for selected examples chosen from elimination methods (linear systems), least squares (filters), linear programming, incidence matrices (networks and graphs), diagonalization (convolution), sparse matrices (partial differential equations).

Prerequisite: COSC 71 or ENGS 91. Students are to be familiar with approximation theory, error analysis, direct and iterative technique for solving linear systems, and discretization of continuous problems to the level normally encountered in an undergraduate course in numerical analysis.

ENGG 107 Bayesian Statistical Modeling and Computation

Not offered 2018–2019

This course will introduce the Bayesian approach to statistical modeling as well as the computational methods necessary to implement models for research and application. Methods of statistical learning and inference will be covered for a variety of settings. Students will have the opportunity to apply these methods in the context of their own research or area of application in the form of a term project.

Prerequisites: ENGS 93 or comparable course in probability and statistics; previous programming experience with Matlab, C, S, R or similar language. (MATH/COSC 71, ENGS 91, COSC 70/170 are appropriate ways to fulfill the programming requirement.)

ENGS 108 Applied Machine Learning

(Identical to QBS 108)

Offered: 18F, 19F: 12

This course will introduce students to modern machine learning techniques as they apply to engineering and applied scientific and technical problems. Techniques such as recurrent neural networks, deep learning, reinforcement learning and online learning will be specifically covered. Theoretical underpinnings such as VC-Dimension, PAC Learning and universal approximation will be covered together with applications to audio classification, image and video analysis, control, signal processing, computer security and complex systems modeling. Students will gain experience with state-of-the-art software systems for machine learning through both assignments and projects. Because of the large overlap in material covered, no student will receive credit for both ENGS 108 and COSC 74/174.

Prerequisites: ENGS 20 or equivalent, MATH 22 or equivalent, ENGS 27 or ENGS 93 or equivalent.

Instructor: Cybenko

ENGS 110 Signal Processing

Offered: 19S, 20S: 10

Continuous and discrete-time signals and systems. The Discrete Fourier Transform and the Fast Fourier Transform. Linear filtering of signals and noise. Characterization of random signals using correlation functions and power spectral densities. Problems will be assigned that require the use of the computer.

Prerequisite: ENGS 32 and ENGS 92 or equivalents

Instructor: Hansen

ENGS 111 Digital Image Processing

Offered: 19S: 9L

Digital image processing has come into widespread use in many fields, including medicine, industrial process monitoring, military and security applications, as well as satellite observation of the earth. This course will cover many aspects of image processing that students will find valuable in their research or personal interest. Topics will include: image sources, computer representation of images and formats, operations on images, and image analysis. In this course we will stretch the conventional notion of images from 2D pixel arrays to include 3D data sets, and we will explore how one can process such stacks of voxels to produce useful information. This course will also touch on some advanced topics in image processing, which may vary based on students interests. This course will require the completion of a project selected by the student.

Prerequisites: ENGS 92 and ENGS 93 or equivalents

Instructor: Hartov

ENGS 112 Modern Information Technologies

Offered: 19S, 20S: 11

This course covers current and emerging information technologies, focusing on their engineering design, performance and application. General topics such as distributed component and object architectures, wireless networking, web computing and information security will be covered. Specific subjects will include Java, CORBA, JINI public key cryptography, web search engine theory and technology, and communications techniques relevant to wireless networking such as Code Division Multiple Access protocols and cellular technology.

Prerequisite: ENGS 20, ENGS 93 and ENGS 27 or COSC 60. ENGS 93 can be taken concurrently.

Instructor: Santos

ENGS 114 Networked Multi-Agent Systems

Not offered 2018–2019

Design and analysis of networked systems comprised of interacting dynamic agents will be considered. Inspired by the cohesive behavior of flocks of birds, we design self-organizing engineering systems that mimic a sense of coordinated motion and the capability of collaborative information processing similar to flocks of birds. Examples include multi-robot networks, social networks, sensor networks, and swarms. The course combines concepts in control theory, graph theory, and complex systems in a unified framework.

Prerequisite: ENGS 26, MATH 23, or equivalents plus familiarity with MATLAB

ENGS 115 Parallel Computing

Not offered 2018–2019

Parallel computation, especially as applied to large scale problems. The three main topics are: parallel architectures, parallel programming techniques, and case studies from specific scientific fields. A major component of the course is laboratory experience using at least two different types of parallel machines. Case studies will come from such applications areas as seismic processing, fluid mechanics, and molecular dynamics.

Prerequisite: ENGS 91 (or COSC 71 or equivalent)

ENGS 116 Computer Engineering: Computer Architecture

(Identical to COSC 251)

Not offered 2018–2019

This course provides an introduction to the field of computer architecture. The history of the area will be examined, from the first stored program computer to current research issues. Topics covered will include successful and unsuccessful machine designs, cache memory, virtual memory, pipelining, instruction set design, RISC/CISC issues, and hardware/software tradeoffs. Readings will be from the text and an extensive list of papers. Assignments will include homework and a substantial project, intended to acquaint students with open questions in computer architecture.

Prerequisite: ENGS 31 and COSC 51; COSC 57, COSC 58, or equivalent recommended

ENGS 120 Electromagnetic Waves: Analytical and Modeling Approaches

Offered: 19W, 20W: 2

Conceptual development, analysis, and modeling in electromagnetic wave propagation, including boundary conditions, material properties, polarization, radiation, scattering, and phased arrays; emerging research and applications in the areas of electromagnetic and materials.

Prerequisite: ENGS 64 or equivalent

Instructor: Luke

ENGG 122 Advanced Topics in Semiconductor Devices

Offered: 18F: arrange

The MOS device structure is the backbone of nearly all modern microelectronics. In this course the gate-insulator-semiconductor structure, commonly referred to as the metal-oxide-semiconductor or MOS structure, will be studied. The historical background of MOS devices and their fabrication will be briefly reviewed, as well as the basic MOS structure for accumulation, depletion and inversion. Advanced issues such as work function, trapped charge, interface traps, non-equilibrium operation and re-equilibration processes will be covered. Analysis of MOS in 1D including capacitance will be performed. The MOSFET will be analyzed with attention on short-channel effects, scaling, drain-induced barrier lowering, etc. The relationship between physics-based MOS device analysis and TCAD modelling will be explored. Other devices utilizing the MOS concept will be discussed, including power devices, CCDs and imaging devices, and FINFETs. The effects of radiation and other reliability issues will also be addressed.

Prerequisite: ENGS 60 or equivalent

Instructor: Fossum

ENGS 123 Optics

(Identical to PHYS 123)

Offered: 19S: arrange

The physical principles and engineering applications of optics, with an emphasis on optical systems. Geometric optics: ray tracing, first-order analysis, imaging, radiometry. Wave optics: polarization, interference, diffraction, Fourier optics. Sources and detectors. Fiber optic systems.

Prerequisite: ENGS 23 or PHYS 41, and ENGS 92 or equivalent

Instructor: Luke

ENGS 124 Optical Devices and Systems

(Identical to PHYS 124)

Not offered 2018–2019

Light has now taken its place beside electricity as a medium for information technology and for engineering and scientific instrumentation. Applications for light include telecommunications and computers, as well as instrumentation for materials science, biomedical, mechanical and chemical engineering. The principles and characteristics of lasers, detectors, lenses, fibers and modulators will be presented, and their application to specific optical systems introduced. The course will be taught in an interdisciplinary way, with applications chosen from each field of engineering. Students will choose design projects in their field of interest.

*Prerequisite: ENGS 23***ENGS 125 Power Electronics and Electromechanical Energy Conversion**

Offered: 18F, 19F: 10

Controlled use of energy is essential in modern society. As advances in power electronics extend the capability for precise and efficient control of electrical energy to more applications, economic and environmental considerations provide compelling reasons to do so. In this class, the principles of power processing using semiconductor switching are introduced through study of pulse-width-modulated dc-dc converters. High-frequency techniques such as soft-switching are analyzed. Magnetic circuit modeling serves as the basis for trans-former, inductor, and electric machine design. Electromechanical energy conversion is studied in relation to electrostatic and electromagnetic motor and actuator design. Applications to energy efficiency, renewable energy sources, robotics, and micro-electromechanical systems are discussed. Laboratory exercises lead to a project involving switching converters and/or electric machines.

Prerequisite: ENGS 23 and ENGS 32

Instructor: Stauth

ENGS 126 Analog Integrated Circuit Design

Offered: 19S, 20S: 2A

Design methodologies of very large scale integration (VLSI) analog circuits as practiced in industry will be discussed. Topics considered will include such practical design considerations as size and cost; technology processes; modeling of CMOS, bipolar, and diode devices; advanced circuit simulation techniques; basic building blocks; amplifiers; and analog systems. A design project is also required in which the student will design, analyze, and optimize a small analog or mixed analog/digital integrated circuit. This design and some homework assignments will require the student to perform analog and digital circuit simulations to verify circuit operation and performance. Lectures will be supplemented by guest lecturers from industry.

Prerequisite: ENGS 32 and ENGS 61, or permission of instructor

Instructor: Odame

ENGS 128 Advanced Digital System Design

Offered: 19S: 2

Field-programmable gate arrays (FPGAs) have become a major fabric for implementing digital systems, rivaling application-specific integrated circuits (ASICs) and microprocessors/microcontrollers, particularly in applications requiring special architectures or high data throughput, such as digital signal processing. Hardware description languages (HDLs) have become the dominant method for digital system design. This course will advance the student's understanding of FPGA design flow and ability to perform HDL-based design and implementation on FPGAs. Topics include: FPGA architectures, digital arithmetic, pipelining and parallelism, efficient design using register transfer level coding and IP cores, computer-aided tools for simulation, synthesis, and debugging. The course is graded on a series of laboratory exercises and a final project. Enrollment is limited to 20 students.

Prerequisite: ENGS 31 and ENGS 62 or COSC 51

Instructor: Hansen

ENGS 129 Biomedical Circuits and Systems

(Can be used by undergraduates for AB course count only)

Offered: 19S, 20S: 11

This course covers the fundamental principles of designing electronic instrumentation and measurement systems, including (i) operation and use of a range of transducers (ii) design of sensor interface circuits (iii) operation and use of different analog-to-digital converters (iv) signal processing algorithms and (v) event-driven microcontroller programming. While these engineering principles will be illustrated in the context of biomedical applications, they are equally relevant to other instrumentation and measurement scenarios. In the first half of the course, there are weekly labs during which students build various biomedical devices, such as an ECG-based heart rate monitor, an electronic stethoscope and an automatic blood pressure monitor. Each of these labs underscores a specific principle of instrumentation and measurement system design. The second half of the course is focused on a group project to build a single, moderately-complex piece of instrumentation, such as a blood oxygenation monitor.

Prerequisite: ENGS 31, ENGS 32 and either ENGS 61 or ENGS 62

Instructor: Odame

ENGS 130 Mechanical Behavior of Materials

Offered: 18F: 10 20S: arrange

A study of the mechanical properties of engineering materials and the influence of these properties on the design process. Topics include tensorial description of stress and strain, elasticity, plastic yielding under multiaxial loading, flow rules for large plastic strains, microscopic basis for plasticity, viscoelastic deformation of polymers, creep, fatigue, and fracture.

Prerequisite: ENGS 24 and ENGS 33, or equivalent

Instructor: Schulson

ENGS 131 Science of Solid State Materials

Offered: 18F, 19F: 2

This course provides a background in solid state physics and gives students information about modern directions in research and application of solid state science.

The course serves as a foundation for more advanced and specialized courses in the engineering of solid state devices and the properties of materials. The main subjects considered are crystal structure, elastic waves-phonons, Fermi-Dirac and Bose-Einstein statistics, lattice heat capacity and thermal conductivity, electrons in crystals, electron gas heat capacity and thermal conductivity, metals, semiconductors, superconductors, dielectric and magnetic properties, and optical properties. Amorphous solids, recombination, photoconductivity, photoluminescence, injection currents, semiconductor lasers, high temperature superconductors, and elements of semiconductor and superconductor microelectronics are considered as examples.

Prerequisite: ENGS 24 or PHYS 24 or CHEM 76 or equivalent

Instructor: Liu

ENGS 132 Thermodynamics and Kinetics in Condensed Phases

Offered: 19W, 20W: 9L

This course discusses the thermodynamics and kinetics of phase changes and transport in condensed matter, with the objective of understanding the microstructure of both natural and engineered materials. Topics include phase equilibria, atomic diffusion, interfacial effects, nucleation and growth, solidification of one-component and two-component systems, solubility, precipitation of gases and solids from supersaturated solutions, grain growth, and particle coarsening. Both diffusion-assisted and diffusion-less or martensitic transformations are addressed. The emphasis is on fundamentals. Applications span the breadth of engineering, including topics such as polymer transformations, heat treatment of metals, processing of ceramics and semiconductors. Term paper.

Prerequisite: ENGS 24 and ENGS 25, or equivalent

Instructor: Schulson

ENGS 133 Methods of Materials Characterization

(Identical to PHYS 128 and CHEM 137)

Offered: 19S, 20S: 2A

This survey course discusses both the physical principles and practical applications of the more common modern methods of materials characterization. It covers techniques of both microstructural analysis (OM, SEM, TEM, electron diffraction, XRD), and microchemical characterization (EDS, XPS, AES, SIMS, NMR, RBS and Raman spectroscopy), together with various scanning probe microscopy techniques (AFM, STM, EFM and MFM). Emphasis is placed on both the information that can be obtained together with the limitations of each technique. The course has a substantial laboratory component, including a project involving written and oral reports, and requires a term paper.

Prerequisite: ENGS 24 or permission

Instructor: I. Baker

ENGS 134 Nanotechnology

Offered: 19W, 20W: 10A

Current papers in the field of nanotechnology will be discussed in the context of the course material. In the second half of the term, students will pick a topic of interest and have either individual or small group meetings to discuss literature and research opportunities in this area. The students will prepare a grant proposal in their area of interest.

Prerequisite: ENGS 24 or PHYS 19 or CHEM 6, or equivalent

Instructor: Liu

ENGS 135 Thin Films and Microfabrication Technology

Offered: 20W: 2

This course covers the processing aspects of semiconductor and thin film devices. Growth methods, metallization, doping, insulator deposition, patterning, and analysis are covered. There are two major projects associated with the course—an experimental investigation performed in an area related to the student's research or interests, and a written and oral report on an area of thin film technology.

Prerequisite: ENGS 24 or equivalent

Instructor: Levey

ENGG 138 Corrosion and Degradation of Materials

(Can be used by undergraduates for AB course count only)

Offered: 19S: 12

Application of the thermodynamics and kinetics of electrochemical reactions to the understanding of such corrosion phenomena as oxidation, passivity, stress corrosion cracking, and corrosion fatigue. Discussion of methods of corrosion control and prevention, including alloy selection, environmental control, anodic and cathodic protection, and protective coatings. Some treatment of the environmental degradation of non-metals and polymers. Applications to current materials degradation problems in marine environments, petrochemical and metallurgical industries, and energy conversion systems.

Prerequisites: ENGS 24 and CHEM 5

Instructor: Li

ENGS 142 Intermediate Solid Mechanics

Offered: 19W, 20W: 3B

Exact and approximate solutions of the equations of elasticity are developed and applied to the study of stress and deformation in structural and mechanical elements. The topics will include energy methods, advanced problems in torsion and bending, stress concentrations, elastic waves and vibrations, and rotating bodies. Although most applications will involve elastic deformation, post-yield behavior of elastic-perfectly plastic bodies will also be studied. The course will also include numerous applications of finite element methods in solid mechanics.

Prerequisite: ENGS 71 or ENGS 76 or equivalent

Instructor: Chen

ENGS 145 Modern Control Theory

Offered: 19S, 20S: 10A

A continuation of ENGS 26, with emphasis on digital control, state-space analysis and design, and optimal control of dynamic systems. Topics include review of classical control theory; discrete-time system theory; discrete modeling of continuous-time systems; transform methods for digital control design; the state-space approach to control system design; optimal control; effects of quantization and sampling rate on performance of digital control systems. Laboratory exercises reinforce the major concepts; the ability to program a computer in a high-level language is assumed.

Prerequisite: ENGS 26

Instructor: Phan

ENGS 146 Computer-Aided Mechanical Engineering Design

Offered: 19S, 20S: 2A

An investigation of techniques useful in the mechanical design process. Topics include computer graphics, computer-aided design, computer-aided manufacturing, computer-aided (finite element) analysis, and the influence of manufacturing methods on the design process. Project work will be emphasized. Enrollment is limited to 24 students.

Prerequisite: ENGS 76

Instructor: Diamond

ENGS 147 Mechatronics

Offered alternate years: 20S: 3A

Mechatronics is the systems engineering approach to computer-controlled products. This course will integrate digital control theory, real-time computing, software design, sensing, estimation, and actuation through a series of laboratory assignments, complementary lectures, problem sets, and a final project. Topics covered will include microprocessor based real-time computing, digital control, state estimation, signal conditioning, sensors, autonomous navigation, and control architectures for autonomous systems. Enrollment is limited to 18 students.

Prerequisite: ENGS 26 or ENGS 145 and two of ENGS 31, ENGS 32, ENGS 33, ENGS 76 or equivalent

Instructor: Ray

ENGG 148 Structural Mechanics

(Can be used by undergraduates for AB course count only)

Offered: 19W: 10A

Development and application of approximate and "exact" analytical and computational methods of analysis to a variety of structural systems, including trusses, two- and three-dimensional frames, plates and/or shells. Modeling of structural systems as one and multi degree of freedom lumped systems permits analysis under a variety of dynamic loads as well as providing an introduction to vibration analysis.

Prerequisite: ENGS 33

Instructor: Phan

ENGG 149 Introduction to Systems Identification

Offered: 20W: 10A

This course provides the fundamentals of system identification theory and its applications to mechanical, electrical, civil, and aerospace systems. Several state-of-the-art identification algorithms in current engineering practice will be studied. The following topics are covered: discrete-time and continuous-time models, state-space and input-output models, Markov parameters, observer Markov parameters, discrete Fourier transform, frequency response functions, singular value decomposition, least-squares parameter estimation, minimal realization theory, observer/Kalman filter identification, closed-loop system identification, nonlinear system identification, recursive system identification, and introduction to adaptive control.

Prerequisites: ENGS 22 and ENGS 26, or equivalent

Instructor: Phan

ENGS 150 Intermediate Fluid Mechanics

Offered: 20S: 10

Following a review of the basic equations of fluid mechanics, the subjects of potential flow, viscous flows, boundary layer theory, turbulence, compressible flow, and wave propagation are considered at the intermediate level. The course provides a basis for subsequent more specialized studies at an advanced level.

Prerequisite: ENGS 25, ENGS 34, or permission of the instructor

Instructor: Meyer

ENGS 151 Environmental Fluid Mechanics

Offered: 19W: 2A

Applications of fluid mechanics to natural flows of water and air in environmentally relevant systems. The course begins with a review of fundamental fluid physics with emphasis on mass, momentum and energy conservation. These concepts are then utilized to study processes that naturally occur in air and water, such as boundary layers, waves, instabilities, turbulence, mixing, convection, plumes and stratification. The knowledge of these processes is then sequentially applied to the following environmental fluid systems: rivers and streams, wetlands, lakes and reservoirs, estuaries, the coastal ocean, smokestack plumes, urban airsheds, the lower atmospheric boundary layer, and the troposphere. Interactions between air and water systems are also studied in context (for example, sea breeze in the context of the lower atmospheric boundary layer).

Prerequisite: ENGS 25, ENGS 34, and ENGS 37, or equivalent

Instructor: Cushman-Roisin

ENGS 152 Magnetohydrodynamics

(*Identical to PHYS 115*)

Offered: 20S: arrange

The fluid description of plasmas and electrically conducting fluids including magnetohydrodynamics and two-fluid fluid theory. Applications to laboratory and space plasmas including magnetostatics, stationary flows, waves, instabilities, and shocks.

Prerequisite: PHYS 68 or equivalent, or permission of the instructor

Instructor: Staff

ENGS 153 Computational Plasma Dynamics

(*Identical to PHYS 118*)

Offered: 19W: arrange

Theory and computational techniques used in contemporary plasma physics, especially nonlinear plasma dynamics, including fluid, particle and hybrid simulation approaches, also linear dispersion codes and data analysis. This is a “hands-on” numerical course; students will run plasma simulation codes and do a significant amount of new programming (using Matlab).

Prerequisite: PHYS 68 or equivalent with ENGS 91 or equivalent recommended, or permission of the instructor

Instructor: Staff

ENGS 154 Aircraft Design

Offered: 19S: 11

This project-based course immerses students in the clean-sheet design of a remotely-controlled aircraft. Students design and fabricate their aircraft from scratch, self-identify gaps in knowledge, and seek out information from a variety of sources. Class periods involve guided discovery of the physical principles of flight, as well as the development and use of mathematical models for design calculations. Assignments focus on the information and calculations needed to model and design the aircraft. This course calls upon material across multiple engineering disciplines: systems engineering; aerodynamics; structural analysis; flight stability and control; and propulsion.

Prerequisite: ENGS 34 and one of ENGS 26, ENGS 31, ENGS 33. Equivalent courses allowed by permission.

Instructor: Epps

ENGS 155 Intermediate Thermodynamics

Offered: 19S, 20S: arrange

The concepts of work, heat, and thermodynamic properties are reviewed. Special consideration is given to derivation of entropy through information theory and statistical mechanics. Chemical and phase equilibria are studied and applied to industrial processes. Many thermodynamic processes are analyzed; the concept of exergy (availability) is used to evaluate their performance, and identify ways to improve their efficiency.

Prerequisite: ENGS 25

Instructor: Frost

ENGS 156 Heat, Mass, and Momentum Transfer

Offered: 19S: 9L

Fundamentals of convection, conduction, radiation, mass, and momentum transport. Basic conservation laws and rate equations in laminar and turbulent flows. Exact solutions. Approximate solutions using boundary layer or integral techniques. Empirical methods. Analysis of engineering systems.

Prerequisite: ENGS 25, ENGS 34

Instructor: Staff

ENGS 157 Chemical Process Design

Offered: 19W, 20W: 10

An in-depth exposure to the design of processes featuring chemical and/or biochemical transformations. Topics will feature integration of unit operations, simulation of system performance, sensitivity analysis, and system-level optimization. Process economics and investment return will be emphasized, with extensive use of the computer for simulation and analysis.

Prerequisite: ENGS 36

Instructor: Laser

ENGS 158 Chemical Kinetics and Reactors

Offered: 19S, 20S: 12

The use of reaction kinetics, catalyst formulation, and reactor configuration and control to achieve desired chemical transformations. The concepts and methods of analysis are of general applicability. Applications include combustion, fermentations, electrochemistry, and petrochemical reactions.

Prerequisite: ENGS 36

Instructor: Laser

ENGS 159 Molecular Sensors and Nanodevices in Biomedical Engineering

Offered: 19S, 20S: 10

Introduction to fundamentals and major types of molecular sensor systems, scaling laws of device miniaturization, and detection mechanisms, including molecular capture mechanisms; electrical, optical, and mechanical transducers; micro-array analysis of biomolecules; semiconductor and metal nanosensors; microfluidic systems; and micro-electromechanical systems (MEMS, BioMEMS) design, fabrication and applications for bioengineering.

Three lab sessions are designed to gain hands-on experience on microfluidic chip and soft lithography, gold nanorods-based biomolecular sensors, micro-reactors using colloidal chemistry in engineering of nanoparticles for biomedical applications in sensing and imaging.

Prerequisite: ENGS 22, CHEM 6, or equivalent

Instructor: Zhang

ENGS 160 Biotechnology and Biochemical Engineering

Offered: 18F, 19F: 9L, lab

A graduate section of ENGS 35 involving a project and extra class meetings.

Not open to students who have taken ENGS 35. Enrollment is limited to 6.

Prerequisite: MATH 3, CHEM 5, BIOL 12 or BIOL 13 and permission of the instructor

Instructor: Gerngross

ENGS 161. Metabolic Engineering

Offered 19W: 12

A consideration of analysis and manipulation of metabolism pursuant to applied objectives. We will start with an overview of cellular metabolism and physiology, first from an extracellular perspective and then from an intracellular perspective, with a focus on unicellular microorganisms. Techniques of quantitative intracellular analysis and metabolic pathway engineering will be considered in some detail, followed by genome editing and applications to the human body. A quantitative perspective will be taken throughout, with frequent reference to examples from the primary literature.

Prerequisites: Engineering Sciences 35/160 and a non-introductory course in biochemistry or molecular biology, or permission.

Instructors: Olson

ENGS 162 Basic Biological Circuit Engineering (pending approval)

Offered: 19W, 20W: 11

This course will provide a comprehensive introduction to the design, modeling, and experimental implementation of synthetic bio-molecular circuits in living cells. Simple but sophisticated synthetic biological circuits will be implemented and tested in microbial cells in the laboratory including those involving molecular amplification, regulatory feedback loops with biological nonlinearities, and robust analog circuits. Computer aided design, modeling, and simulation will use CADENCE, an industry standard electronic circuit design tool showing how to design, model, and fit actual experimental biological data such that engineering circuit theory and biological experiment agree.

Prerequisite: MATH 3 or MATH 8 or equivalent experience in Basic Calculus, CHEM 5, BIOL 13. Experience in Molecular Biology is useful (e.g. ENGS 35, BIOL 45, & BIOL 46 or equivalent) but not necessary. Experience in Signals and System Modeling is also useful (e.g. ENGS 22) but not necessary.

Instructor: Sarpeshkar

ENGS 163 Advanced Protein Engineering

(Not open to AB and BE students. Students in these degree programs are encouraged to enroll in ENGS 58)

Offered: 19W, 20W: 3B

This course will build on molecular engineering fundaments introduced in ENGS58 and equip students to formulate novel engineered molecules by translating methods into practical design proposals. The three components of any protein engineering effort will be surveyed: host strain, library design, and selective pressure. Both gold standard and novel engineering methodologies will be studied, and tradeoffs among different techniques will be examined through detailed case studies. Data presentation and interpretation skills will be developed by examining current literature focused on proteins with practical utility.

Prerequisite: ENGS 58, OR ENGS 160, OR BIOCHEM 101. Equivalent courses accepted with instructor's permission.

Instructor: Ackerman

ENGS 164 Medical Diagnostics and Monitoring (pending approval)

19W: arrange

Diagnostics from all aspects of healthcare will be evaluated with an emphasis on cross-cutting healthcare areas in infectious diseases, oncology, cardiology, and neurology. Foundational principles cover concepts central to microbiology, chemistry, nucleic acid and imaging technologies as well as the importance of quality assurance and quality control. Topics covered include the clinical trial system and FDA approval pathways for drugs and devices. Expert guest lecturers from Thayer, Geisel, The Dartmouth Institute, Dartmouth Hitchcock Medical Center and the White River Junction Veterans Administration Medical Center will present on specialized topic areas. Field trips. This course might appeal to students seeking to advance their knowledge of the medical devices field, including those in bioengineering, biotechnology, the applied sciences, and business-oriented students.

Prerequisite: ENGS 35 or equivalent

Instructor: Hill

ENGS 165 Biomaterials

Offered: 19S, 20S: T, Th 8:00–9:50

Consideration of material problems is perhaps one of the most important aspects of prosthetic implant design. The effects of the implant material on the biological system as well as the effect of the biological environment on the implant must be considered. In this regard, biomaterial problems and the bioelectrical control systems regulating tissue responses to cardiovascular and orthopedic implants will be discussed. Examples of prosthetic devices currently being used and new developments of materials appropriate for future use in implantation will be taken from the literature.

Prerequisite: ENGS 24, or equivalent

Instructor: Van Citters

ENGG 166 Quantitative Human Physiology

(Can be used by undergraduates for AB course count only)

Not offered 2018–2019

Introduction to human physiology using the quantitative methods of engineering and physical science. Topical coverage includes cellular membrane ion transport, Hodgkin-Huxley models and action potentials, musculoskeletal system, cardiovascular physiology, respiratory physiology, and nervous system physiology. Laboratory exercises and a final project delve into the measurement of human physiology, data analysis, and model testing.

*Prerequisite: ENGS 22 or equivalent; BIOL 12 or BIOL 14 or ENGS 30; ENGS 23 or MATH 23 or PEMM 101***ENGS 167 Medical Imaging**

Offered: 18F: 9L

A comprehensive introduction to all major aspects of standard medical imaging systems used today. Topics include radiation, dosimetry, x-ray imaging, computed tomography, nuclear medicine, MRI, ultrasound, and imaging applications in therapy. The fundamental mathematics underlying each imaging modality is reviewed and an engineering picture of the hardware needed to implement each system is examined. The course will incorporate a journal club review of research papers, term tests, and a term project to be completed on an imaging system.

Prerequisite: ENGS 92 (may be taken concurrently)

Instructor: Pogue

ENGG 168 Biomedical Radiation Transport

Offered: 19F: 9L

This course will provide a general overview of radiation transport mechanisms in matter, beginning with a derivation of the Boltzmann radiation transport equation, and examining the various approximations possible. Focus on the single-energy Diffusion approximation will be examined in detail, as it relates to neutron diffusion nuclear reactors and optical photon diffusion. Review of photon diffusion in tissue will be discussed as it relates to tissue spectroscopy and imaging. Fundamental research papers in this field will be presented and reviewed, covering aspects of multiple scattering, Mie scattering, and scattering phase functions. Stochastic model-based approaches will be covered as well, such as the Monte Carlo model. Numerical approaches to solving these models will be introduced.

Prerequisite: ENGS 23 or equivalent

Instructor: Pogue

ENGS 169 Intermediate Biomedical Engineering

Offered: 19S: 10

A graduate section of ENGS 57. Students taking the course for graduate credit will be expected to write a research proposal aimed at developing a specific surgical technology. Groups of 2-3 students will work together. The proposal will require an extensive literature review, a detailed proposal of research activities, alternative methods, and timeline, and a detailed budget and budget justification for meeting the research objectives. Weekly meetings will take place between the groups and Professor Halter to discuss progress. By the end of the term the groups are expected to have a complete proposal drafted. Enrollment is limited to 18 students. Not open to students who have taken ENGS 57.

Prerequisite: ENGS 23 and ENGS 56 or equivalent

Instructor: Halter

ENGS 170 Neuroengineering

Offered: 19W: 2A

This course will introduce students to currently available and emerging technologies for interfacing with the human brain. Students will study the fundamental principles, capabilities and limitations of a range of relevant technologies within the scope of noninvasive brain-computer interfaces, neural implants, neurostimulation, sensory substitution and neuroinformatics. The ethical and societal ramifications of these technologies will also be considered. Applications of neuroengineering technology in medicine will be emphasized such as the diagnosis and treatment of neurological diseases and neural rehabilitation.

Prerequisite: ENGS 22 and ENGS 56

Instructor: Diamond

ENGS 171 Industrial Ecology

Offered: 19W, 20W: arrange

By studying the flow of materials and energy through industrial systems, industrial ecology identifies economic ways to lessen negative environmental impacts, chiefly by reducing pollution at the source, minimizing energy consumption, designing for the environment, and promoting sustainability. The objective of this course is to examine to what extent environmental concerns have already affected specific industries, and where additional progress can be made. With the emphasis on technology as a source of both problems and solutions, a broad spectrum of industrial activities is reviewed ranging from low-design high-volume to high-design low-volume products.

Students activities include a critical review of current literature, participation in class discussion, and a term project in design for the environment.

Prerequisite: ENGS 21 and ENGS 37

Instructor: Faludi

ENGS 172 Climate Change and Engineering

Offered: 19W: 2A

Earth's climate is result of interplay between continental and moving atmospheric and oceanic systems with multiple forcing mechanisms and internal feedbacks. Fundamental heat, mass, and radiative transfer processes impacting the climate system will be examined to understand the drivers of current and past climate. Published regional and global impact projections and adaptation strategies for the future will be examined. Mitigation and sustainable energy will be investigated, and choices on the international, national and local scales will be discussed. Students will be required to actively participate in class by leading class discussions and actively engaging in small group activities. In addition, students will conduct a research project to design an adaptation and mitigation strategy for a community or business in a region of their choice, and will write a term paper and make an oral presentation of their findings

Prerequisites: ENGS 151 or ENGS 156 or EARS 178, or equivalent.

Instructor: Albert

ENGG 173 Energy Utilization

Offered: 19W, 20W: 10A

Industrial societies are presently powered primarily by fossil fuels. Continuing to supply energy at the rate it is now used will be problematic, regardless of the mix of fossil fuels and alternatives that is used; yet western consumption patterns spreading through the rest of the world and other trends portend large increases in demand for energy services. Increased energy efficiency will be essential for meeting these challenges, both to reduce fossil-fuel consumption and to make significant reliance on alternatives feasible. Technical issues in efficient systems for energy utilization will be surveyed across major uses, with in-depth technical analysis of critical factors determining possible, practical, and economical efficiency improvements in both present technology and potential future developments. Areas addressed include lighting, motors and drive systems, heating, ventilation and air conditioning, transportation, appliances and electronics.

Prerequisites: ENGS 22 and at least two of the following: ENGS 25, ENGS 32, ENGS 34, ENGS 44, ENGS 52, ENGS 76, ENGS 104, ENGS 125, ENGS 150, ENGS 155, ENGS 156, and ENGM 184, or permission. ENGS 25 is strongly recommended.

Instructor: Sullivan

ENGG 174 Energy Conversion

Offered: 18F, 19F: 11

This course will address the science and technology of converting key primary energy sources—fossil fuels, biomass, solar radiation, wind, and nuclear fission and fusion—into fuels, electricity, and usable heat. Each of these topics will be analyzed in a common framework including underlying fundamentals, constraints on cost and performance, opportunities and obstacles for improvement, and potential scale.

Prerequisites: ENGS 22 and at least two of the following: ENGS 25, ENGS 32, ENGS 34, ENGS 36, ENGS 44, ENGS 52, ENGS 76, ENGS 104, ENGS 125, ENGS 150, ENGS 155, ENGS 156, and ENGM 184, or permission. ENGS 25 is strongly recommended.

Instructor: Laser

ENGS 175 Energy Systems

Offered: 19S, 20S: 2A

A consideration of energy futures and energy service supply chains at a systemic level. Dynamic development of demand and supply of primary energy sources and key energy carriers will be considered first assuming continuation of current trends, and then with changes to current trends in order to satisfy constraints such as limiting carbon emissions and changing resource availability. Integrated analysis of spatially-distributed time-variable energy systems will also be addressed, with examples including generation, storage, and distribution of electricity and production of energy from biomass.

Prerequisites: ENGS 25, ENGS 51, either ENGG 173 or ENGG 174 or permission of the instructor

Instructors: Farid

ENGG 176 Design for Manufacturing

Not offered 2018–2019

Design for Manufacturing (DFM) is an analysis-supported design approach in which analytical models incorporating manufacturing input are used at the earliest stages of design in order to influence part and product design towards those design choices that can be produced more easily and more economically. DFM analysis addresses any aspect of the developing design of parts in which the issues of manufacturing are involved. The designed object is considered explicitly through its geometries and material selection and their impact on manufacturing costs. This course is intended primarily for students interested in mechanical, industrial, and manufacturing engineering, as well as for engineering design practitioners in industry. The course will emphasize those processes most often used in the mass production of consumer products and will include such processes as assembly, injection molding, die casting, stamping and forging.

Prerequisite: ENGS 73 or permission of instructor

ENGG 177 Decision-Making under Risk and Uncertainty

Not offered 2018–2019

Making decisions under conditions of risk and uncertainty is a fundamental part of every engineer and manager's job, whether the situation involves product design, investment choice, regulatory compliance, or human health and safety. This course will provide students with both qualitative and quantitative tools for structuring problems, describing uncertainty, assessing risks, and reaching decisions, using a variety of case studies that are not always amenable to standard statistical analysis. Bayesian methods will be introduced, emphasizing the natural connections between probability, utility, and decision-making.

Prerequisites: ENGS 27, ENGS 93, or comparable background in probabilistic reasoning

ENGM 178 Technology Assessment

(Cannot be used to satisfy any AB degree requirements)

Offered: 18F: W, F 8:30–10:00 19F: arrange

This project course is grounded in technology-focused areas and provides an opportunity for teams of students to conduct a thorough analysis of prevalent and emerging technologies in fields of critical interest such as health, energy, the environment, and other complex systems and then to recommend and justify actions for its further development. Technology in an assigned application field will be analyzed by each student team, along with emerging, complementary and competing technologies, leading to 1) findings of those impediments and incentives for its further development, 2) identification and quantification of the societal and/or commercial benefits achievable from further development, and 3) recommendations for action in research funding, product and market development, public policy, and the like, that would most rapidly achieve the identified societal and/or commercial benefits.

No prerequisite

Instructors: Bish

ENGM 179 Financial and Managerial Accounting

Offered: 19W, 20W: arrange

Accounting is the accumulation, reporting, and analysis of a company's financial data. It is used by both external decision makers, such as creditors and investors, and internal decision makers, from product line managers to the board of directors. This course develops the basic concepts underlying corporate financial statements, such as overhead allocation and product costing. It also introduces tools used by both external and internal decision makers to analyze and use accounting information.

No prerequisite

Instructors: Sansing

ENGM 180 Corporate Finance

(Cannot be used to satisfy any AB degree requirements)

Offered: 19S, 20S: arrange

Issues of financial management important to the engineering manager. A review of the concepts of engineering economy, including time value of money, net present value, and choosing among investment alternatives. Discussion of global and national economic factors impacting the modern technology-driven corporation—such as exchange rates, competitiveness, cost of capital, money markets, and tax policies. Examination of the role of the financial organization in a corporation and its relationship to the engineering manager. Evaluating a balance sheet and an income statement; understanding the effect of mergers, acquisitions, leveraged buyouts, and venture capital on R&D organizations. Discussion of the financial aspects of engineering project management, including planning and budgeting, project costing, and cost vs. schedule vs. performance trade-offs. One or several additional topics, such as defense industry economics, impacts of deregulation, intellectual property law, and economic forecasting, will be selected for discussion.

Prerequisite: ENGM 179 or permission of instructor

Instructors: Severino

ENGM 181 Marketing

(Cannot be used to satisfy any AB degree requirements)

Offered: 18F: M 10:00–11:30 and 1:00–2:30 19F: arrange

This course introduces the role of marketing within business firms. Case studies drawn from a wide variety of consumer and industrial products and services provide an opportunity for students to apply concepts and techniques developed in assigned readings. Specific topics include customer analysis, market research, market segmentation, distribution channel policy, product policy and strategy, pricing, advertising, and sales force management. The course stresses oral and written expression and makes use of several computer exercises, spreadsheet analysis, and management simulations.

Prerequisite: Permission of instructor

Instructor: Staff

ENGM 182 Data Analytics

Offered: 19S, 20S: arrange

This course provides a hands-on introduction to the concepts, methods and processes of business analytics. Students learn how to obtain and draw business inferences from data by asking the right questions and using the appropriate tools. Topics include data preparation, statistical tools, data mining, visualization, and the overall process of using analytics to solve business problems. Students work with real-world business data and analytics software. Where possible, cases are used to motivate the topic being covered. Students acquire a working knowledge of the "R" language and environment for statistical computing and graphics. Prior experience with "R" is not necessary, but students should have a basic familiarity with statistics, probability, and be comfortable with basic data manipulation in Excel spreadsheets.

Prerequisite: ENGS 93 or equivalent or permission of the instructor

Instructor: Parker

ENGM 183 Operations Management

(Cannot be used to satisfy any AB degree requirements)

Offered: 19S, 20S: arrange

This course provides an introduction to the concepts and analytic methods that are useful in understanding the management of a firm's operations. We will introduce job shops, assembly lines, and continuous processes. Other topics include operations strategy, aggregate planning, production scheduling, inventory control, and new manufacturing technologies and operating practices.

Prerequisite: ENGS 93

Instructor: Debo

ENGM 184 Introduction to Optimization Methods

(Cannot be used to satisfy any AB degree requirements)

Offered: 18F, 19F: 10A

An introduction to various methods of optimization and their use in problem solving. Students will learn to formulate and analyze optimization problems and apply optimization techniques in addition to learning the basic mathematical principles on which these techniques are based. Topic coverage includes linear, nonlinear, and dynamic programming, and combinatorial optimization.

No prerequisite

Instructor: Lasky

ENGM 185 Topics in Manufacturing Design and Processes

(Cannot be used to satisfy any AB degree requirements)

Offered: 19W, 20W: arrange

The course will consist of four main topics: 1) technical estimating, 2) design of experiments, 3) design for manufacturability, 4) statistical process control. We will review technical estimating (TE), a vital skill in today's rapidly changing industry. Illustrative and interesting examples will be used to hone TE techniques. Design of experiments (DOE) will be covered in detail using Montgomery's Design and Analysis of Experiments. Analysis of variance, model adequacy checking, factorial designs, blocking and confounding, regression models, nesting, and fractional factorial and Taguchi designs will be taught. Design for manufacturability (DFM) will be covered so that by the end of the course the student will know how to establish a successful DFM program to optimize and continuously improve designs and manufacturing processes. Cost estimating related to manufacturing processes will also be presented, followed by an overview of failure analysis techniques. The course will also introduce the basics of statistical process control, including the Shewhart Rules.

Prerequisite: ENGS 93

Instructor: Lasky

ENGM 186 Technology Project Management

(Cannot be used to satisfy any A.B. degree requirements)

Offered: 19W: arrange

Project management focuses on planning and organizing as well as directing and controlling resources for a relatively short-term project effort which is established to meet specific goals and objectives. Project management is simultaneously behavioral, and quantitative, and systematic. The course covers topics in planning, scheduling and controlling projects such as in new product development, technology installation, and construction. This course is aimed at both business and engineering students and combines reading and case-oriented activities.

Prerequisite: ENGM 184 or equivalent

Instructor: Bish

ENGM 187 Technology Innovation and Entrepreneurship

(Cannot be used to satisfy any AB degree requirements)

Offered: 19W, 20W: arrange

Innovation is the process of translating a new invention or discovery into a commercial product. In this course, some of the guiding principles in technology innovation and entrepreneurship are discussed. The principles encompass intellectual property including patents, product definition including minimal viable product and whole product, customer definition and focus, product development, marketing and sales and communication, and manufacturing. Financial modelling and funding sources are addressed. Leadership practices including hiring, team building, employees, outsourcing and working with investors are also discussed. Students will prepare papers on various topics, make presentations, and create a real or hypothetical business plan as part of the coursework.

No prerequisite

Instructor: Fossum

ENGM 188 Law for Technology and Entrepreneurship

(Cannot be used to satisfy any AB degree requirements)

Offered: 18F, 19F: M, Tu 8:30–10:00

The solutions to many of the challenges of entrepreneurship in general, and to those of starting up a technologically based business in particular, are provided by the law. A grounding in the law of intellectual property, contractual transactions, business structures, debt and equity finance, and securities regulation, both in the U.S. and in an international context, will help inventors and entrepreneurs to manage this part of the process intelligently and with a high likelihood of success.

No prerequisite

Instructor: Goodenough

ENGM 189 Medical Device Development

(Cannot be used to satisfy any AB degree requirements)

(This course carries .5 credit)

Offered: 18F, 19F: M, Tu 1:15–2:45

This course is an overview of existing medical devices and discusses methods for development, evaluation and approval of new medical devices. The course will cover both diagnostic and interventional devices, and cover clinical and pre-clinical testing issues, as well as a discussion of FDA approval processes, funding startups, and cost effectiveness analysis. The course will involve several case studies as examples. For projects, students will work in teams to analyze needs in the medical setting and come up with a plan for a new device, and analyze how best to develop it with a new startup. Two classes per week, 5 weeks total.

Prerequisite: Graduate standing in engineering or business administration

Instructor: Paulsen

ENGM 190 Platform Design, Management, and Strategy

Offered: 18F: M 6:00–9:00 PM 19F: arrange

This course is aimed at students, managers, executives, investors, and entrepreneurs interested in creating, managing, or understanding business platforms. Firms such as Amazon, Apple, Facebook, SalesForce, and SAP operate as ecosystems in which third parties add value. Topics include startup, converting existing businesses, openness, network effects, innovation, cannibalization, pricing, governance, and competition. The course will combine rigorous theory with real-world experience. Case studies will emphasize practical approaches and draw from social media, healthcare, entrepreneurship, enterprise software, mobile services, and consumer products to provide foundations and definitions. This course will also demonstrate established economic principles from the literature on industrial organization, two-sided network effects, information asymmetry, agency, pricing, and game theory. A basic background in microeconomics is recommended as a prerequisite.

Platforms are economically important and widely observed in modern economies. For example, HMOs match patients and physicians. Real estate and auction networks match buyers and sellers. Airline reservation systems match travelers to airline flights. However, thanks largely to technology, platforms are becoming much more prevalent. New platforms are being developed and traditional businesses are being reconceived as platforms e.g. U.S. Postal Service, newspapers (Huffington Post). Retail electric markets are evolving into platforms that match consumers with specific power producers, allowing them to express their preferences for source of supply. In creating strategies for platform markets, managers have typically relied on assumptions and paradigms that apply to businesses without network effects. As a result, they have made decisions in pricing, supply chains, product design, and strategy that are inappropriate for the economics of their changing industries.

No prerequisite

Instructor: Parker

ENGG 192 Independent or Group Study in Engineering Sciences

(Cannot be used to satisfy any A.B. degree requirements. May not be used for term-length research or design projects.)

Offered: all terms: arrange

An independent study course in lieu of, or supplementary to, a 100-level course, as arranged with a faculty member. To be used in satisfaction of advanced degree requirements, requests for approval must be submitted to the Thayer School graduate program director no later than the end of the first week of classes in the term in which the course is to be taken. No more than one such course should be used in satisfaction of requirements for any degree. Proposed courses should include full syllabus, resources and student evaluation methods.

ENGG 194 PhD Oral Qualifier

(Cannot be used to satisfy any AB, BE, MEM, MEng, or MS degree requirements)

Offered: arrange

The oral qualifying exam, a set of questions put forward by an oral examination committee to the candidate, normally takes place before or during the fifth term of the student's program, or, in exceptional circumstances, early in the sixth term. The exam is open to the faculty, but not to the general public.

The committee tests the candidate's knowledge of principles and methods underlying the field in which advanced work is to be performed. The exam covers material selected by the candidate's advisor in consultation with the examining committee, and includes coverage of mathematical techniques appropriate to the research area. The structure of the preparation for the exam is flexible.

The examination committee consists of 4 members: the chair plus 3 Dartmouth faculty examiners, with at least 2 of the examiners from Thayer School. A Thayer faculty member other than the student's advisor chairs the committee. This chair is assigned by the director of the M.S. and Ph.D. programs.

The examination committee gives the student a pass, fail, or conditional pass result. Students who fail may retake the oral examination—one time only—within the following 3 months. No third attempt is allowed.

ENGG 195 Seminar on Science, Technology, and Society

(Cannot be used to satisfy any AB, BE, MEM, MEng, or MS degree requirements)

Offered: 18F, 19W, 19S: arrange

Presentation and discussion of timely issues in scientific and technological development and its relation to society. Topics vary from year to year. Examples include transition for scientific developments to technological developments and impacts of technological development on various aspects of society; ethics, social issues, environmental concerns, and government policy; entrepreneurship, marketing, labor markets, quality, international competition, and legal liability. Students will be required to sign up for and participate in 2-3 lunches with Jones Seminar speakers each term, and you have the choice of which speakers you would like to have lunch with. At the start of each term, we will circulate a Google spreadsheet of the speakers with roughly 10 sign up slots for each, and you will be able to select which lunches you would like to participate in. The group meets for lunch with the Jones Seminar speaker and later in the day attends the Jones Seminar. The students are expected to read the material submitted by the speaker and to have prepared questions for the lunch meeting. Discussion will be moderated by the instructor. The grade for this seminar will be based on attendance and participation in the discussions. A few weeks of absence are permitted for illness or travel due to scholarly work as needed.

Prerequisite: Ph.D. student standing

Instructor: MS/PhD director

ENGG 197 PhD Professional Workshops

(Cannot be used to satisfy any AB, BE, MEM, MEng, or MS degree requirements)

Offered: 19W: arrange

A sequence of workshops on the preparation for professional life after the PhD program, culminating in the completion of a curriculum vitae or resume, outline of possible jobs, and a competitive grant proposal. A major goal is for the student to design and write a grant for a technology startup program or for an academic research grant. Successful research and SBIR proposals are outlined and the processes for evaluating them are offered by research principal investigators, grant administration officials, and corporate representatives. Both academic CVs and industry resumes can be developed. Workshops include job search guides, management skills and research team management. Submitted student proposals and CVs are critiqued for improvement.

Prerequisite: PhD student standing

Instructor: MS/PhD director

ENGG 198 Research-In-Progress Workshop

(Cannot be used to satisfy any AB, BE, MEM, MEng, or MS degree requirements)

Offered: 19W: arrange

Annual meeting of all doctoral candidates in residence with each candidate presenting in generally understandable terms his or her research progress over the past year.

Prerequisite: PhD student standing

Instructor: MS/PhD director

ENGG 199 Special Topics in Engineering Sciences

(Cannot be used to satisfy any AB degree requirements)

Offered: all terms: arrange

A special topics lecture course in lieu of, or supplementary to, a 100-level course, as arranged by a faculty member to be used in satisfaction of advanced degree requirements. The course must be approved by the graduate programs committee in advance of the term in which it is offered. No more than two such courses should be used in satisfaction of requirements for any degree. To permit action prior to the term's end, requests for approval must be submitted to the graduate director no later than the eighth week of the term preceding the term in which the course is to be offered. Proposed courses should include full syllabus, resources, and student evaluation methods. Courses that have a 100-level prerequisite should use ENGG 299.

ENGS 200 Methods in Applied Mathematics II

(Identical to PHYS 110)

Not offered 2018–2019

Continuation of ENGS 100 with emphasis on variational calculus, integral equations, and asymptotic and perturbation methods for integrals and differential equations.

Selected topics include functional differentiation, Hamilton's principle, Rayleigh-Ritz method, Fredholm and Volterra equations, integral transforms, Schmidt-Hilbert theory, asymptotic series, methods of steepest descent and stationary phase, boundary layer theory, WKB methods, and multiple-scale theory.

Prerequisite: ENGS 100, or equivalent

Instructor: Staff

ENGS 202 Nonlinear Systems

Not offered 2018–2019

The course provides basic tools for modeling, design, and stability analysis of nonlinear systems that arise in a wide range of engineering and scientific applications including robotics, autonomous vehicles, mechanical and aerospace systems, nonlinear oscillators, chaotic systems, population genetics, learning systems, and networked complex systems. There are fundamental differences between the behavior of linear and nonlinear systems. Lyapunov functions are powerful tools in dealing with design and stability analysis of nonlinear systems. After addressing the basic differences between linear and nonlinear systems, the course will primarily focus on normal forms of nonlinear systems and Lyapunov-based control design methods for a variety of applications with an emphasis on robotics, mechanical control systems, and particle systems in potential fields.

Prerequisite: ENGS 100 and ENGS 145 or equivalents and familiarity with MATLAB

ENGS 205 Computational Methods for Partial Differential Equations II**Offered:** 20S: arrange

Boundary Element and spectral methods are examined within the numerical analysis framework established in ENGS 105. The boundary element method is introduced in the context of linear elliptic problems arising in heat and mass transfer, solid mechanics, and electricity and magnetism. Coupling with domain integral methods (e.g. finite elements) is achieved through the natural boundary conditions. Extensions to nonlinear and time-dependent problems are explored. Spectral methods are introduced and their distinctive properties explored in the context of orthogonal bases for linear, time-invariant problems. Extension to nonlinear problems is discussed in the context of fluid mechanics applications. Harmonic decomposition of the time-domain is examined for nonlinear Helmholtz-type problems associated with EM and physical oceanography.

Prerequisite: ENGS 105

Instructor: Paulsen

ENGG 210 Spectral Analysis

(Can be used by undergraduates for AB course count only)

Not offered 2018–2019

An advanced treatment of digital signal processing for the analysis of time series. A study is made of parametric and nonparametric methods for spectral analysis. The course includes a review of probability theory, statistical inference, and the discrete Fourier Transform. Techniques are presented for the digital processing of random signals for the estimation of power spectra and coherency. Examples are taken from linear system theory and remote sensing using radar. Laboratory exercises will be assigned requiring the use of the computer.

Prerequisite: ENGS 110**ENGG 212 Communications Theory**

(Can be used by undergraduates for AB course count only)

Not offered 2018–2019

An advanced treatment of communications system engineering with an emphasis on digital signal transmission. The course includes a review of probability theory, random processes, modulation, and signal detection. Consideration will be given to channel modeling, the design of optimum receivers, and the use of coding.

Prerequisite: ENGS 110**ENGS 220 Electromagnetic Wave Theory****Not offered 2018–2019**

Continuation of ENGS 120, with emphasis on fundamentals of propagation and radiation of electromagnetic waves and their interaction with material boundaries. Propagation in homogeneous and inhomogeneous media, including anisotropic media; reflection, transmission, guidance and resonance, radiation fields and antennas; diffraction theory; scattering.

Prerequisite: ENGS 100 and ENGS 120 or permission of the instructor**ENGG 230 Fatigue and Fracture**

(Can be used by undergraduates for AB course count only)

Offered: 19W: arrange

A study of the fracture and fatigue behavior of a wide range of engineering materials (metals, ceramics, polymers, biological materials, and composites). Topics include work of fracture, fracture mechanics (linear elastic, elastic-plastic and plastic), fracture toughness measurements, crack stability, slow crack growth, environmentally assisted cracking, fatigue phenomenology, the Paris Law and derivatives, crack closure, residual stress effects, and random loading effects. These topics will be presented in the context of designing to avoid fracture and fatigue.

Prerequisite: ENGS 130 or permission of instructor

Instructor: Frost

ENGG 240 Kinematics and Dynamics of Machinery

(Can be used by undergraduates for AB course count only)

Not offered 2018–2019

A study of kinematics, dynamics, and vibrations of mechanical components. Topics will include kinematic analysis and synthesis of mechanisms, with applications to linkages, cams, gears, etc.; dynamics of reciprocating and rotating machinery; and mechanical vibrations. Computer-aided design and analysis of kinematic and kinetic models.

Prerequisite: ENGS 72

ENGS 250 Turbulence in Fluids

Not offered 2018–2019

An introduction to the statistical theory of turbulence for students interested in research in turbulence or geophysical fluid dynamics. Topics to be covered include the statistical properties of turbulence; kinematics of homogeneous turbulence, phenomenological theories of turbulence; waves, instabilities, chaos and the transition to turbulence; analytic theories and the closure problem; diffusion of passive scalars; and convective transport.

Prerequisite: ENGS 150 or equivalent

ENGG 260 Advances in Biotechnology

Offered: 18F, 19F: arrange 19W, 20W: arrange 19S, 20S: arrange

Biotechnology continues to undergo explosive and transformative growth. Our fundamental knowledge of biological systems, which underlies modern biotechnology, is now being updated and revised on a daily basis. Likewise, instrumentation and biological tools are experiencing a continuous revolution that pushes the boundaries of applied biology. To be competitive within their professions, biotechnologists and biological engineers must therefore maintain broad knowledge of current advances in fields related to their areas of specialization. This course will survey current peer-reviewed literature from a variety of sources and help students develop good reading habits, literature search skills, and the ability to critically assess peer-reviewed literature.

Prerequisites: Graduate standing and ENGS 160 or ENGS 163

Instructors: Ackerman, Griswold

ENGG 261 Biomass Energy Systems

(Can be used by undergraduates for AB course count only)

Offered: 20W: arrange

Biocommodity engineering is concerned with the biological production of large-scale, low unit value commodity products including fuels, chemicals, and organic materials. Intended primarily for advanced graduate students and drawing extensively from the literature, this course considers the emergence of biocommodity engineering as a coherent field of research and practice. Specific topics include feedstock and resource issues, the unit operations of biocommodity engineering—pretreatment, biological processing, catalytic processing, and separations—and the design of processes for biocommodity products.

Prerequisite: ENGS 157 and ENGS 161 and permission of instructor

Instructor: Lynd

ENGS 262 Advanced Biological Circuit Engineering (pending approval)

Offered: 19S, 20S: 11

This course will provide advanced techniques for the design, modeling, and experimental implementation of complex synthetic biological circuits including feedback control and regulation. Advanced & complex synthetic circuits will be designed and tested in bacteria in the laboratory. Computer aided design, modeling, and simulation will use CADENCE, an industry standard electronic circuit design tool. Applications of synthetic biology to medicine and biotechnology will be discussed. In addition, the students will be expected to design a synthetic biological circuit with feedback and control techniques for a class project.

Prerequisite: ENGS 162 (Basic Biological Circuit Engineering); OR Equivalent experience in Molecular Biology Techniques (Either ENGS 35, BIOL 45, BIOL 46) AND equivalent experience in Signals and System Modeling (e.g. ENGS 22).

Instructor: Sarpeshkar

ENGG 296 Graduate Research (1 credit)**ENGG 297 Graduate Research (2 credits)****ENGG 298 Graduate Research (3 credits)****ENGG 299 Advanced Special Topics in Engineering Sciences**

(Cannot be used to satisfy any AB degree requirements)

Offered: all terms: arrange

A special topics course in lieu of, or supplementary to, a 200-level course, as arranged by a faculty member, to be used in satisfaction of degree requirements. The course must be approved by the graduate programs committee in advance of the term in which it is offered. No more than one such course may be used in satisfaction of requirements for any degree. Requests for approval must be submitted to the program director no later than the eighth week of the term preceding the term in which the course is to be offered, to permit action prior to the term's end. Proposed courses should include full syllabus, resources and student evaluation methods. Courses that do not have a 100-level prerequisite should use ENGG 199.

ENGG 300 Enterprise Experience Project

Offered: all terms: arrange

Hands-on experience with existing enterprises can create a valuable training and enrichment experience for students in the Thayer graduate programs. For this course, you will propose and arrange a paid or unpaid internship in an existing enterprise (industry, government or other) in consultation with your faculty advisor prior to enrollment. Enrollment is concurrent with the internship and should be for a period of one quarter. At the end of the internship, you will make a presentation to the Thayer community that addresses the nature of the enterprise you were engaged in, the problem you were assigned, and the results and impact of your project. The purpose of the presentation is to share lessons learned from the experience with the Thayer community. The presentation will be accompanied by a short but complete written report. Neither the presentation nor report should contain confidential information of the enterprise.

An Internship Proposal form is required prior to committing to an internship, and must be signed by your faculty advisor and the instructor. The forms are available in the Thayer School Registrar's Office. The course is graded on a credit/no credit basis by the instructor after completion of the report. Enrollment is open to MS and PhD students that have completed at least three (3) quarters of program residency. Students may enroll in the course more than once, but students holding F-1 visas should consult with OVIS.

Instructor: Fossum

ENGG 309 Topics in Computational Science

(Cannot be used to satisfy any AB degree requirements.)

Offered: arrange

Contemporary theory and practice in advanced scientific computation, organized by physical application area. Course comprises two 5-week modules, selected from the following:

Computational Fluid Dynamics. This module covers four basic contemporary issues: (i) the inherent nonlinearity of fluids; (ii) the mixed hyperbolic/elliptic nature of the differential equations governing fluid motion; (iii) the concomitant algorithmic complexity of their numerical treatment; and (iv) the size, i.e., the large number of degrees of freedom found in most realistic problems. Discussion of advection-dominated flows: physical and numerical properties; temporal and spatial discretization issues; method of characteristics, upwinding, Galerkin and Petrov-Galerkin methods; artificial viscosity. Navier-Stokes and shallow water equations in 2- and 3-D: mixed interpolation; primitive equation and higher-order formulation; staggered meshes; boundary conditions on pressure, transport and stress; radiation conditions. Frequency domain solution of hyperbolic problems: nonlinear generation of harmonics; truncation errors in iterative methods

Prerequisites: ENGS 34 and ENGS 105, or equivalent

Instructor: Staff

Computational Solid Mechanics. This module will deal with the development and application of finite element methods for solid mechanics problems. After a brief treatment of the theory of elasticity, the finite element equations for elastic solids will be developed using variational techniques. Applications in two- and three-dimensional static elasticity will be considered. Techniques will then be developed to analyze the following classes of problems; nonlinear material behavior, especially plasticity; plates and shells; problems involving contact between two bodies; and dynamic analysis of elastic bodies.

Prerequisites: ENGS 33 and ENGS 105, or equivalent

Instructor: Staff

Computational Electromagnetics. This module focuses on numerical solutions of the Maxwell equations. Emphasis will be placed on problem formulation and implementation issues. Examples will be selected from a broad spectrum of topics such as electromagnetic scattering, waveguides, microwave circuits and strip-lines, bioelectromagnetics. Development of software to solve representative problems will be required. It is anticipated that the student will be capable of reading and understanding the current computational electromagnetics literature upon completion of this course.

Prerequisites: ENGS 105 and ENGS 120

Instructor: Staff

ENGG 310 Advanced Topics in Signals and Systems

(Cannot be used to satisfy any AB degree requirements)

Offered: arrange

Advanced study in signal processing and system theory. Possible topics include multi-input/multi-output systems, two-dimensional systems (image processing), modeling and identification, optimal filtering, and advanced optics. Readings in current research literature and student presentations.

Prerequisites: Different for each topic; normally include ENGS 123 and ENGG 210 or equivalent, and permission of instructor

Instructor: Hansen

ENGG 312 Topics in Statistical Communication Theory

(Cannot be used to satisfy any AB degree requirements)

Offered: arrange

Advanced study in any of the following or other topics may be pursued: information theory, coding, noise, random signals, extraction of signals from noise, pattern recognition, and modulation theory. Normally offered in alternate years.

Prerequisites: ENGS 93, ENGS 110, and permission of instructor

Instructor: Cybenko

ENGG 317 Topics in Digital Computer Design

(Cannot be used to satisfy any AB degree requirements)

Offered: arrange

Critical analysis of current literature in an emerging area of digital technology, such as multi-processor architecture, decentralized networks of small computers, bubble memories, ultra-fast arithmetic logic, specialized computers for digital filtering, etc. A term paper will be required.

Prerequisites: ENGS 116 and permission of instructor

Instructor: Cybenko

ENGG 321 Introduction to Innovation**Offered:** 18F, 19F: arrange

ENGG 321 provides students in the PhD Program in Innovation with experience in the process of commercializing a new technology. During the fall (or winter) term, the students act as faculty assistants for ENGS 21 to provide a learning experience in oversight of various projects. During the winter term, students meet on a weekly basis to discuss a variety of reading assignments in innovation and enterprise building. During the spring term, students choose a technology to commercialize, typically from their own dissertation research efforts. During that term students develop a full enterprise plan for commercialization of the technology, including IP issues and strategy, applications, market forecasting and strategy, product development plans, a full multi-year monthly financial cost plan for all aspects of the enterprise, and a resource plan including personnel and funding. Students meet weekly and make installment presentations to their classmates and instructor for discussion and modification. Ad hoc discussion of related issues to running an enterprise, such as team building and personnel, infrastructure, funding options, whole product, and the "chasm" between invention and product, also takes place. The spring term is an intensive experience and students should reserve sufficient time for the course activity. At the end of the spring term students will present their enterprise plan to a review panel of internal and external seasoned entrepreneurs and an audience of IP Fellows for feedback and discussion.

Prerequisites: ENGM 188; ENGM 180 recommended; a proposal for research of a specific new technology must be developed and approved by the course faculty prior to the fall term.

ENGG 197, taken in the winter term, is a co-requisite.

NOTE: Students in the PhD Program in Innovation normally take this course during the third year of the program when their research is sufficiently advanced to have the prerequisite proposal for new technology. PhD students not admitted to the Innovation program may request to enroll in this class in addition to their required courses. Because of the reduced frequency of meeting, credit is given for only one course, one-half for the fall term and one-half for the spring term.

Instructor: Fossum

ENGG 324 Microstrip Lines and Circuits

(Cannot be used to satisfy any AB degree requirements)

Offered: arrange

Analysis of transmission structures and circuit elements at microwave frequencies. Microwave network representation. Characterization and sensitivities of transmission structure. Discontinuities. Two-dimensional planar components. Models for microwave semiconductor devices. Microwave networks.

Prerequisites: ENGS 61, ENGS 105, ENGS 120, and permission of instructor

Instructor: Trembly

ENGG 325 Introduction to Surgical Innovation

(This course is designed to replace the research experience ENGG 296)

Offered: 18F, 19F: arrange 19W, 20W: arrange 19S, 20S: arrange

Analysis of transmission structures and circuit elements at microwave frequencies. Introduction to Surgical Innovation will engage students in an immersive experience, a cornerstone technique for innovative thinking and creative design. It comprises of three 10-week terms over one academic year (fall/general surgery, winter/surgical elective, and spring/surgical research). Student effort is approximately 20 hours per week (15 hours of activity and 5 hours to prepare assignments, read, think, and write). This unique course provides experiential learning on the life cycle of surgical devices, including: (1) defining a clinical need; (2) consideration of surgical risks and benefits from a patients point of view; (4) steps in the surgical procedure that could benefit from innovation to improve patient outcomes or make the procedure easier to perform; (5) managing surgical implants and instruments from a surgical scrub technologist's point of view; (6) steps in surgical device procurement, processing, packaging, sterilization, and inventory management; (7) post-surgical patient care and device performance surveillance.

The course begins in the *fall term* with a general surgery rotation. Engineering doctoral TSI (Training in Surgical Innovation) students work alongside 3rd year medical students and surgical residents. Each morning they attend the daily conference (e.g., indications, morbidity & mortality, journal club, tumor board, or grand rounds, 3-5h/wk). TSI students participate in the weekly medical student case discussion (2h) and also the weekly surgical resident simulation bioskills workshop (2h). Each student is assigned a surgeon proctor to help them navigate the clinical environment and understand context. Each week the student observes at least one outpatient clinic patient encounter (1-2h) and one surgical procedure (3-5h) with the proctor or another surgeon colleague arranged through the proctor. The outpatient clinic encounters focus on pre-operative patients to observe surgical consent discussions and post-operative patients to highlight surgical outcomes ascertainment and adverse event surveillance. On the day of surgery, the student arrives early to meet the surgical scrub technologist and help prepare for the surgery. The student then meets the patient preoperatively with the proctor and observes the surgical procedure from start to finish. The student follows the surgical scrub tech post-operatively to see instrument processing through central supply processing, sterilization and inventory management. Each week the student produces a 1-page write-up identifying opportunities for innovation to improve patient outcomes or ease of performance for the observed surgical procedure. The write-ups are evaluated and scored by Drs. Paulsen and Mirza. The *winter term* has a similar schedule with a different proctor (and set of surgeon colleagues) from a surgical subspecialty of the student's choice, such as minimally invasive general surgery, oncologic surgery, otolaryngology, anesthesiology, neurosurgery or orthopedic surgery. The *spring term* is a research rotation in which students select a clinical mentor and an engineering mentor to guide development of a research proposal. The rotation focuses on medical research methods, including design of clinical trials, evaluation of benefits and harms, and standards for surgical materials/device performance and implant bioeffects. The rotation emphasizes clinical trial design and data analysis from a regulatory perspective. Activities include

engaging clinicians, engineers, other scientists, and the medical device industry to understand relevant FDA regulations and legislation, roles and responsibilities of federal advisory committees, types of applications (PMA/IDE/510k), review and consult processes, and role of device companies. Participants learn about the steps required to develop, protect, and finance an idea as a “laboratory” exercise and work to implement a specific idea (project), culminating in the development of a draft IP position and business plan. The focus of the training experience is on innovation and creation of new technology-driven start-up companies (not on business management). The final written assignment for the Surgical Innovation Course is a 6-page research proposal for development and validation of a novel surgical technology, similar in format to an NIH Small Business Innovation Research (SBIR) grant. The student also attends at least one hospital surgical implant purchasing committee meeting during the term and writes a one-page report on the device procurement decision-making process. Both the purchasing process write-up and research proposal are evaluated and scored by the student’s mentors and also by Drs. Paulsen and Mirza.

Prerequisites: permission of instructor(s)

Instructors: Paulsen, Mirza

ENGG 332 Topics in Plastic Flow and Fracture of Solids

(Cannot be used to satisfy any AB degree requirements)

Offered: arrange

Advanced study may be pursued on topics related to the microscopic aspects of the plastic flow and fracture of solids. The topics extend those introduced in ENGS 130 and ENGS 132 by providing an in-depth examination of the methods of strengthening, brittle and ductile fracture, fatigue, creep, and superplasticity. The emphasis is on the mechanisms underlying the phenomena. Readings in the literature will be assigned, and the student will be required to prepare a detailed term paper.

Prerequisites: ENGS 130, ENGS 132, and permission of instructor

Instructor: Frost

ENGG 339 Advanced Electron Microscopy

(Cannot be used to satisfy any AB degree requirements)

Offered: arrange

Image formation and contrast are discussed for the transmission electron microscope, using both kinematical and dynamical theory. Image simulation methods are outlined and the information from a variety of diffraction methods, such as CBED, are described. Various analytical techniques such as electron energy loss spectroscopy and x-ray fluorescence, including advanced techniques such as ALCHEMI, are covered. Emphasis is placed on the applications, resolution, and theoretical and practical limitations of each technique. There are several laboratory sessions, each requiring a report.

Prerequisite: ENGS 133 or permission of instructor

Instructor: I. Baker

ENGG 365 Advanced Biomaterials

(Cannot be used to satisfy any AB degree requirements.)

Not offered 2018–2019

This course will focus on the interface between the host and implant with greater emphasis on the tissue reaction to metals, ceramics, polymers, bioceramics, and biopolymers than on the effect of the host environment on the materials. Ion release concerns, wear particle reactions, and the potential toxic properties of the salts of implant metals will be analyzed. The cells and cellular reactions available to the host will be evaluated in detail.

Prerequisites: ENGS 165 and permission of instructor

Instructor: Van Citters

ENGG 367 Heat Transfer in Hyperthermia

(Cannot be used to satisfy any AB requirements)

Offered: arrange

Review of coordinate systems, energy conservation equation, and temperature and heat-flux boundary conditions. Capillary blood perfusion as a distributed heat sink. Summary of distributed heat-flux sources associated with one or more of the following: internal and external radio-frequency, ultrasound, and microwave applicators. Surface cooling. Steady-state analytic and numerical solutions to practical problems in one and two dimensions. One or more of these advanced topics: transient responses, large blood vessels as discrete heat sinks, approximate solutions in three dimensions, lumped approximations to distributed systems.

Prerequisites: ENGS 23, ENGS 156, and permission of instructor

Instructor: Trembly

ENGM 387 MEM Professional Skills

(Cannot be used to satisfy any AB, BE, MS, or PhD degree requirements)

Offered: 18F, 19F: arrange

This course develops professional skills required for professional success during and after the MEM program. Skills acquired provide a basis for success in pursuing, securing and performing an internship and a post-graduation job. In a series of workshops, the course targets career self-assessment, ethics, interpersonal, and communication skills. Homework assignments provide practice and feedback for skills learned. ESL (English as a Second Language) support is offered as needed in the context of written and speaking activities of the course.

No prerequisite

ENGG 390 MEM Project

Offered: 19, all terms

An individual engineering project to be completed during any term of the final year of an MEM program. The project should define a practical need and propose a means to satisfy it, display an ability to conceive and evaluate solutions, describe appropriate analytical, experimental, and economic evaluations, and provide recommendations for further action. Projects will normally either have an industrial context or will be related to a specific design objective within a research program at Thayer School.

Prerequisites: ENGM 178 or permission of instructor

Instructor: Parker

Management Courses (Tuck School of Business)

The following examples of Tuck electives are available to MEM students. All courses require permission from the instructor and prior approval of the MEM program director. For this year's list of Tuck management courses, see:
tuck.dartmouth.edu/mba/elective-curriculum/elective-courses

Advanced Competitive Strategy

The Business of Healthcare

Data Mining for Business Analytics

Consulting Project Management

Corporate Communications

Energy Economics

Global Strategy & Implementation

Leadership Out of the Box

Marketing Research

Negotiations

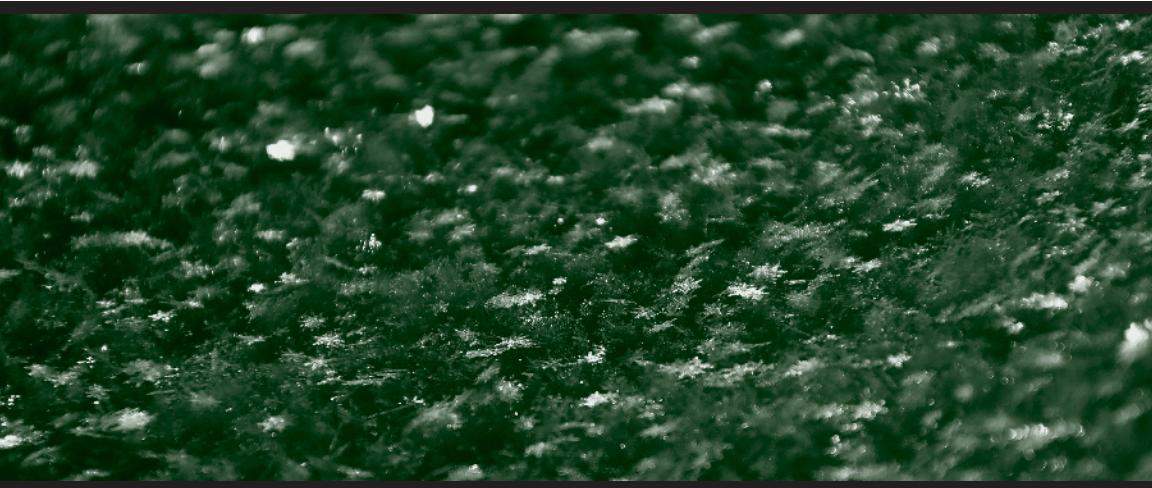
Operations Strategy

Services Operations

Strategic Brand Management

graduate courses

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Snow accumulating on Arctic sea ice during a rare calm day. With high winds in the Arctic, perfect snowflakes are short lived. These fell on a windless day near Barrow, Alaska, covering the entire snow pack in a layer of delicate crystals. Photographed by PhD candidate Nicholas Wright.

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Kristi Clemens

Title IX Coordinator & Clery Act Compliance Officer

Parkhurst Hall, Room 009

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5 Post Office Square, 8th Floor

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Phone: 617-289-0111 | Fax: 617-289-0150

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Evelynn Ellis

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Hanover, NH 03755-3541

Phone: 603-646-3197 | Fax: 603-646-2516

Email: institutional.diversity.&.equity@dartmouth.edu

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TDD: 800.669.6820

Web: eeoc.gov/field/boston/index.cfm

New Hampshire Commission for Human Rights

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Concord, NH 03301

Phone: 603-271-2767 | Fax: 603-271-6339

E-mail: humanrights@nhsa.state.nh.us

Web: nh.gov/hrc

Approved by the Board of Trustees November 7, 2015

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A complete directory of administration and staff is at:
engineering.dartmouth.edu/people/administration/

A password-protected photo directory of students, faculty, and staff is at:
engineering.dartmouth.edu/directory/

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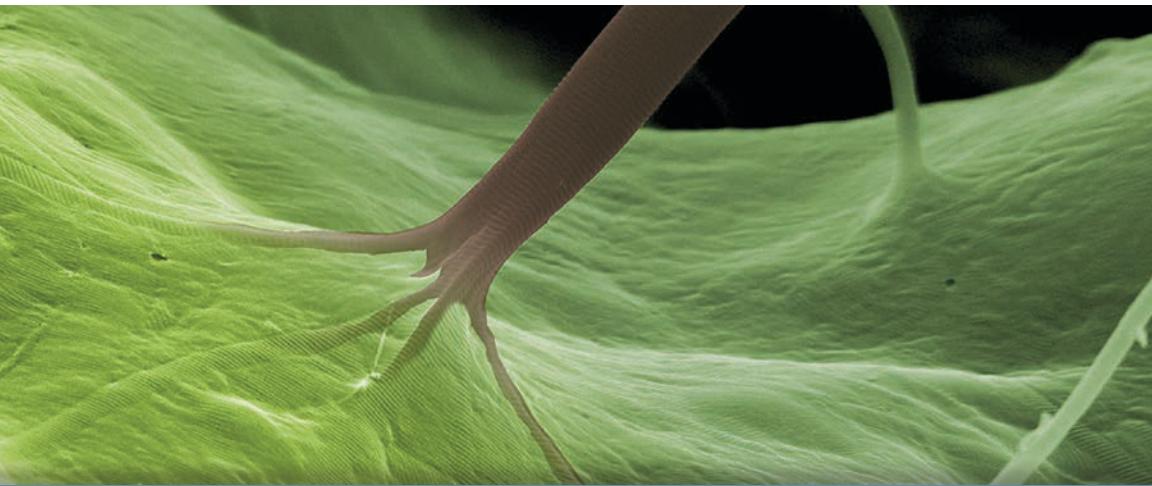
The officers of Dartmouth College believe that the information contained in this Guide to Programs and Courses is accurate as of the date of publication (August 2018), and they know of no significant changes to be made in the near future. However, Dartmouth College and Thayer School of Engineering reserve the right to make such changes in their operations, programs, and activities as the Trustees, overseers, faculty, and officers consider appropriate and in the best interests of the Dartmouth community.

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