2021-2022

GUIDE TO PROGRAMS & COURSES

DARTMOUTH ENGINEERING

Table of Contents

Academic Calendar 2021-2022

engineering.dartmouth.edu/community/calendar

FALL TERM 2021	
September 10	Advising and orientation begin
September 13-15	Fall term online check-in
September 13	Fall term classes begin
September 13-19	First week of fall term Add/Drop period. Permission to add courses is not necessary unless normally required.
September 15	Deadline to complete check-in without a $50 late registration fee. Check-in must be completed by 11:59 p.m.
September 22	Final day for delayed check-in (with $50 late fee). Any student not checked in by the end of this day, but still listed with the enrollment pattern letter R (residence) for the fall term is liable for administrative withdrawal.
October 8-9	Homecoming Weekend
October 22	Course Timetable available for the Winter term
November 2	Final day to withdraw from a course; any later request to withdraw from a course requires petition to a special committee.
November 16	Fall term classes end
November 17-18	Pre-examination break
November 19	Final examinations begin
November 23	Scheduled final examinations end
November 24	Unscheduled final examination day
November 24	Final examinations end
WINTER TERM 2022	
January 3-6	Winter term online check-in
January 4	Winter term classes begin
January 4-10	First week of winter term Add/Drop period. Permission to add courses is not necessary unless normally required.
January 6	Deadline to complete check-in without a $50 late registration fee. Check-in must be completed by 11:59 p.m.
January 13	Final day for delayed check-in (with $50 late fee). Any student not checked-in by the end of this day, but still listed with the enrollment pattern letter R (residence) for the winter term is liable for administrative withdrawal.
January 17	Martin Luther King Jr. Day. Courses regularly held in the 8-, 9-, 10-, 11-, 12-, and 2-sequences moved to their x-periods. Courses held in the 3A-period moved to the 3B-period. Laboratory sections meet as scheduled, unless otherwise notified by the instructor.
February 4	Course Timetable available for the Spring term
February 22	Final day to withdraw from a course; any later request to withdraw from a course requires petition to a special committee.
March 8	Winter term classes end
March 9-10	Pre-examination break
March 11	Final examinations begin
March 14	Scheduled final examinations end
March 15	Unscheduled final examinations day
March 15	Final examinations end

SPRING TERM 2022	
March 27-29	Spring term online check-in
March 28	Spring term classes begin
March 28-April 3	First week of winter term Add/Drop period. Permission to add courses is not necessary unless normally required.Final day for delayed check-in
March 30	Deadline to complete check-in without a $50 late registration fee. Check-in must be completed by 11:59 p.m.
April 6	Final day for delayed check-in (with $50 late fee). Any student not checked-in by the end of this day, but still listed with the enrollment pattern letter R (residence) for the spring term is liable for administrative withdrawal.
April 22	Course Timetable available for Summer term
May 6	Course Timetable available for Fall term
May 18	Final day to withdraw from a course; any later request to withdraw from a course requires petition to a special committee.
May 30	Memorial Day Holiday (no classes held)
June 1	Spring term classes end
June 1	Final day, prior to the start of summer term classes, for making changes in summer and fall term course elections
June 2	Pre-examination break
June 3	Final examinations begin
June 6	Scheduled final examinations end
June 7	Unscheduled final examinations day
June 7	Final examinations end
June 11	Thayer School of Engineering at Dartmouth’s Investiture Ceremony
June 12	Dartmouth Commencement
SUMMER TERM 2022 (Tentative)	
June 23	Summer term classes begin
June 25	Special day of classes
July 4	Independence Day (College Holiday), no classes held
August 24	Summer term classes end
August 27	Final examination period begins
August 29	Scheduled final examinations end
August 30	Final examinations end


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Faculty

Faculty

engineering.dartmouth.edu/community/faculty

Core Faculty

Alexis R. Abramson
Dean and Professor of Engineering

Margie Ackerman
Professor of Engineering
Program Area Lead: Biological and Chemical Engineering

Mary R. Albert
Professor of Engineering
Executive Director, US Ice Drilling Program

Ian Baker
Sherman Fairchild Professor of Engineering
Senior Associate Dean for Research and Graduate Programs

Petra Bonfert-Taylor
Professor of Engineering
Associate Dean for Diversity and Inclusion

Petr Brůža
Assistant Professor of Engineering

Benoit Cushman-Roisin
Professor of Engineering

George Cybenko
Dorothy and Walter Gramm Professor of Engineering

Scott C. Davis
Associate Professor of Engineering

Solomon G. Diamond
Associate Professor of Engineering
Director of the Cook Engineering Design Center

Xiaoyao Fan
Assistant Professor of Engineering

Hui Fang
Associate Professor of Engineering

Amro Farid
Associate Professor of Engineering

Eric R. Fossum
John H. Krehbiel Sr. Professor for Emerging Technologies
Director of the PhD Innovation Program
Vice Provost for Office of Entrepreneurship and Technology Transfer

Harold J. Frost
Associate Professor of Engineering

Tillman U. Gerngross
Professor of Engineering

David Gladstone
Professor of Engineering
Professor of Medicine, Geisel School of Medicine

Britt Goods
Assistant Professor of Engineering

Karl Griswold
Professor of Engineering

Ryan J. Halter
Associate Professor of Engineering

Eric W. Hansen
Associate Professor of Engineering
Director of the Dual-Degree Program

Geoffroy Hautier
Hodgson Family Associate Professor of Engineering

Katherine Hixon
Assistant Professor of Engineering

Shudong Jiang
Professor of Engineering

Klaus Keller
Professor of Engineering

Eugene Korsunskiy
Associate Professor of Engineering

Mark Laser
Associate Professor of Engineering

Ronald C. Lasky
Professor of Engineering

Jiwon Lee
Ralph and Marjorie Crump Assistant Professor of Engineering

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

Weiyang (Fiona) Li
William P. Harris Career Development Assistant Professor of Engineering

Yan Li
Assistant Professor of Engineering

Jifeng Liu
Associate Professor of Engineering
Program Area Lead: Material Science and Engineering

Geoffrey P. Luke
Assistant Professor of Engineering

Lee R. Lynd
Paul E. and Joan H. Queneau Distinguished Professor in Environmental Engineering Design
Adjunct Professor of Biology
Program Area Lead: Energy Engineering

Wesley J. Marrero
Assistant Professor of Engineering

Vicki May
Professor of Engineering

Erin Mayfield
Hodgson Family Assistant Professor of Engineering

Matthew D.J. McGarry
Assistant Professor of Engineering

Paul M. Meaney
Professor of Engineering

Colin R. Meyer
Assistant Professor of Engineering
Academic Cluster: Arctic Engineering in a Period of Climate Change

Sohail K. Mirza
Professor of Engineering

Elizabeth L. Murnane
Charles H. Gaut and Charles A. Norberg Assistant Professor of Engineering

Ethan K. Murphy
Assistant Professor of Engineering

Kofi Odame
Associate Professor of Engineering
Program Area Lead: Electrical and Computer Engineering

Daniel G. Olson
Assistant Professor of Engineering

Geoffrey G. Parker
Professor of Engineering
Director, MEM Program

Keith D. Paulsen
Robert A. Pritzker Chair in Biomedical Engineering
Professor of Radiology, Geisel School of Medicine
Scientific Director of Advanced Imaging Center, Dartmouth-Hitchcock Medical Center
Co-Director of Cancer Imaging and Radiobiology Research Program, Norris Cotton Cancer Center

Donald K. Perovich
Professor of Engineering

Minh Q. Phan
Associate Professor of Engineering

Ulf Österberg
Professor of Engineering

Brian W. Pogue
MacLean Professor of Engineering
Professor of Surgery, Geisel School of Medicine
Co-Director, Translational Engineering in Cancer Research Program, Norris Cotton Cancer Center
Co-Director, Dartmouth Medical Physics PhD Program, Norris Cotton Cancer Center
Program Area Lead: Biomedical Engineering

Laura R. Ray
Professor of Engineering
Senior Associate Dean for Faculty Development

Peter J. Robbie
Associate Professor of Engineering

Kimberley S. Samkoe
Associate Professor of Engineering

Eugene Santos, Jr.
Professor of Engineering

Rahul Sarpeshkar
Thomas E. Kurtz Professor and Chair, Neukom Cluster of Computational Science
Professor of Engineering
Professor of Physics
Professor of Microbiology and Immunology, Geisel School of Medicine
Professor of Molecular and Systems Biology, Geisel School of Medicine

William J. Scheideler
Assistant Professor of Engineering

Erland M. Schulson
George Austin Colligan Distinguished Professor of Engineering
Director, Ice Research Laboratory

Helene Seroussi
Associate Professor of Engineering

Simon G. Shepherd
Professor of Engineering

Fridon Shubitidze
Associate Professor of Engineering

Jason Stauth
Associate Professor of Engineering

Rafe Steinhauer
Assistant Professor of Engineering

Charles R. Sullivan
Professor of Engineering

Stephen Taylor
Professor of Engineering

Douglas W. Van Citters
Associate Professor of Engineering
Associate Dean for Undergraduate Education

Vikrant Vaze
Stata Family Career Development Associate Professor of Engineering
Program Area Lead: Mechanical, Operations, and Systems Engineering

John X.J. Zhang
Professor of Engineering
Program Director for Electrical, Communications and Cyber Systems (ECCS), NSF

Adjunct and Visiting Faculty

Steven Arcone
Adjunct Professor of Engineering
Research Geophysicist, CRREL (retired)

Emily Asenath-Smith
Adjunct Assistant Professor of Engineering
Research Materials Engineer, CRREL

Benjamin Barrowes
Adjunct Assistant Professor of Engineering
Research Physicist, US Army Cold Regions Research and Engineering Laboratory

John-Erik Bell
Adjunct Associate Professor of Engineering

Eric Bish
Visiting Assistant Professor of Engineering

Jay C. Buckey, Jr.
Adjunct Professor of Engineering
Professor of Medicine, Geisel School of Medicine

Peter Chin
Visiting Professor of Engineering

David M. Cole
Adjunct Professor of Engineering
Research Civil Engineer, US Army Cold Regions Research and Engineering Laboratory

Zoe Courville
Adjunct Assistant Professor of Engineering
Research Mechanical Engineer, US Army Cold Regions Research and Engineering Laboratory

Eugene Demidenko
Adjunct Professor of Engineering
Professor of Community and Family Medicine, Geisel School of Medicine

Jonathan T. Elliot
Adjunct Assistant Professor of Engineering
Assistant Professor of Surgery, Geisel School of Medicine

Peter Evans
Visiting Instructor
Managing Partner, Platform Strategy Institute

Jeremy Faludi
Adjunct Assistant Professor of Engineering

Armin R. Fugenschuh
Visiting Professor of Engineering

Oliver Goodenough
Adjunct Professor of Engineering
Professor, Vermont Law School

Richard H. Granger
Adjunct Professor of Engineering
Professor of Psychological and Brain Sciences
Director, The Brain Engineering Laboratory

Richard M. Greenwald
Adjunct Professor of Engineering
Co-Founder and President of Simbex; Co-Founder, iWalk;

Joseph J. Helble
Adjunct Professor of Engineering
President, Lehigh University

Jane Hill
Adjunct Assistant Professor of Engineering

Eric Henderson
Adjunct Associate Professor of Engineering
Associate Professor of Orthopaedic Surgery, Geisel School of Medicine

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

Michael Jermyn
Adjunct Assistant Professor of Engineering

Songbai Ji
Adjunct Associate Professor of Engineering

Stephen C. Kanick
Adjunct Assistant Professor of Engineering

Erik J. Kobylarz
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Professor of Neurology, Geisel School of Medicine

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

Christopher Polashenski
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Frank C. Rafie
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Clinical Assistant Professor of Medicine, Geisel School of Medicine

Carl E. Renshaw
Adjunct Professor of Engineering
Chair and Professor of Earth Sciences, Dartmouth College

David W. Roberts
Adjunct Professor of Engineering
Active Emeritus Professor of Surgery and Neurology, Geisel School of Medicine

Joseph M. Rosen
Adjunct Professor of Engineering
Professor of Surgery, Geisel School of Medicine

Scott A. Snyder
Adjunct Assistant Professor of Engineering
Principal, a.hamalainen design

Harold M. Swartz
Adjunct Professor of Engineering
Professor of Radiology, Geisel School of Medicine
Professor of Community and Family Medicine, Geisel School of Medicine
Professor, The Dartmouth Institute

Elijah Van Houten
Adjunct Associate Professor of Engineering
Senior Lecturer, University of Canterbury

John B. Weaver
Adjunct Professor of Engineering
Professor of Radiology, Geisel School of Medicine

Benjamin B. Williams
Adjunct Associate Professor of Engineering
Associate Professor of Medicine, Geisel School of Medicine
Associate Professor of Radiology, Geisel School of Medicine

Lecturers

Lee Cooper
Lecturer
Biotech investor and entrepreneur

Daniel C. Cullen
Lecturer
Project, Materials, and Fluids Lab Manager at Thayer School of Engineering at Dartmouth

Ross Gortner
Lecturer
Associate Director of MEM Program, Thayer School of Engineering at Dartmouth**Kendall Hoyt**
Senior Lecturer
Assistant Professor of Medicine, Geisel School of Medicine

David Macaulay
Lecturer
Author and Artist

Steven Peterson
Senior Lecture

Markus Testorf
Lecturer

John D. Wilson
Lecturer
Senior Lecturer in the Department of Studio Art, Dartmouth College

Emeriti Faculty

John P. Collier
Myron Tribus Professor of Engineering Innovation, Emeritus

Alvin Omar Converse
Professor of Engineering, Emeritus

Robert C. Dean, Jr.
Adjunct Professor of Engineering, Emeritus

Elsa Garmire
Sydney E. Junkins 1887 Professor, Emerita

Ursula Gibson
Professor of Engineering, Emerita

Robert J. Graves
John H. Krehbiel Sr. Professor for Emerging Technologies, Emeritus

Alexander Hartov
Professor of Engineering, Emeritus

Charles Edgar Hutchinson
Dean and Professor of Engineering, Emeritus

Francis E. Kennedy, Jr.
Professor of Engineering, Emeritus

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

Daniel R. Lynch
MacLean Professor of Engineering, Emeritus

Michael B. Mayor
Adjunct Professor of Engineering, Emeritus

Victor F. Petrenko
Research Professor, Emeritus

Horst J. Richter
Professor of Engineering, Emeritus

Bengt Ulf Östen Sonnerup
Sydney E. Junkins 1887 Professor of Engineering, Emeritus

Graham B. Wallis
Sherman Fairchild Professor of Engineering, Emeritus

Undergraduate Studies

Undergraduate Studies

engineering.dartmouth.edu/undergraduate

Our undergraduate program embraces a systems-based, interdisciplinary approach to equip students with principles from across multiple engineering disciplines that can be applied towards solutions for complex global challenges. At the undergraduate level, engineering courses are offered within the context of Dartmouth's full liberal arts education and a majority of courses involve hands-on, collaborative, project-oriented learning.

Undergraduate Degree Programs

Bachelor of Arts (AB)

engineering.dartmouth.edu/undergraduate/ab

The Engineering Sciences major requires seven prerequisites in mathematics and science, at least nine courses in Engineering Sciences, and all Dartmouth liberal arts requirements. A majority of students who earn the AB also continue their education to earn the professional Bachelor of Engineering (BE) degree from Dartmouth.

Bachelor of Engineering (BE)

engineering.dartmouth.edu/undergraduate/be

The BE degree, a professional degree recognized by the Engineering Accreditation Commission of ABET (abet.org), requires a minimum of nine Engineering Sciences courses beyond the AB degree, with at least six courses with significant engineering design content. Required courses and electives include mathematics, science, Engineering Sciences, and engineering design.

AB+BE Program for Dartmouth Computer Science Majors

engineering.dartmouth.edu/undergraduate/be/examples#computer-science

Dartmouth students interested in computer science and engineering can major in Computer Science modified with Engineering Sciences 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.

AB+BE Program for Dartmouth Physics Majors

engineering.dartmouth.edu/undergraduate/be/examples#Physics

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.

Dual-Degree Program

engineering.dartmouth.edu/academics/undergraduate/dual

Students from colleges and universities other than Dartmouth can combine a bachelor's degree from their home institution with a BE from Thayer School of Engineering at Dartmouth.

Off-Campus Study

Engineering students may pursue a variety of study abroad programs through Thayer or through Guarini Institute for International Education (guarini.dartmouth.edu). Thayer offers a number of international exchange programs specifically for undergraduate engineering students in Denmark, Thailand, Hong Kong, Germany, and New Zealand, as well as a joint engineering and language program in Berlin, with Dartmouth's Department of German Studies. Credits earned as part of off-campus study can be transferred toward either the AB or BE degree.

Planning Ahead

Due to the sequential nature of the Engineering Sciences curriculum, and the possibilities for developing modified majors with other departments, all engineering students benefit greatly from planning ahead.

Planning for the AB + BE

All students are encouraged to meet with faculty advisors as early as possible to plan their course of study, particularly if they are interested in pursuing the Bachelor of Engineering (BE) degree along with the AB and/or if they are also interested in also pursuing a Masters in Engineering Management (MEM) or a higher degree. Prospective BE students should use the BE Program Plan spreadsheet, available on ThayerExpress (express.thayer.dartmouth.edu) to better understand degree requirements and to plan with their advisors their course of study.

Planning for the AB + BE + MEM

Early planning allows students interested in pursuing both the BE and Master of Engineering Management (MEM) to complete the AB, BE, MEM program in six years. Delaying planning until after the start of the BE program will likely lengthen the completion time for the MEM degree. Students may apply for admission to the MEM program while enrolled as an undergraduate at Dartmouth.

Academic Honor Principles and Code of Conduct

All students, upon matriculation, sign an agreement to abide by the academic honor principles and code of conduct established by Dartmouth College. **AB candidates** can find the academic honor principles and code of conduct on Dartmouth's Community Standards page (students.dartmouth.edu/community-standards). **BE candidates** are also bound by Thayer's academic honor principles and code of conduct, found in the Graduate Student Handbook on ThayerExpress (express.thayer.dartmouth.edu).

Bachelor of Arts (AB)

engineering.dartmouth.edu/undergraduate/ab

The Bachelor of Arts degree is awarded by Dartmouth College, and details for the requirements for the Bachelor of Arts degree can be found in the "Organization, Regulations, and Courses" Catalog from Dartmouth's Office of the Registrar: (dartmouth.smartcatalogiq.com/current/orc.aspx).

A majority of Engineering Sciences majors also pursue additional coursework required for the Bachelor of Engineering (BE), a professional engineering degree awarded by the Thayer School of Engineering. Students are encouraged to work closely with their faculty advisors to develop a multi-year course progression plan that will meet both AB and BE degree requirements.. (See page **48** for more information about the BE program).

Majors and Minors

Prerequisites

All Engineering Sciences majors, modified majors, and minors must take prerequisite courses in Mathematics, Physics, Computer Science, or Chemistry, as guided by their degree programs. First-year students should take the placement test in Mathematics during orientation week. Prerequisite courses can be taken under the Non-Recording Option with the exception of courses taken to fulfill requirements for a major or minor and unless otherwise prohibited.

Curriculum Overview

The Engineering Sciences curriculum immerses students in the work of applying engineering theory to practical problems. In all courses, students practice critical thinking and communications, skills that mark the highly valued professional engineer.

- **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.

Program Areas

Under a unified department of Engineering Sciences, Dartmouth promotes collaborative synergies between engineering disciplines through six **Program Areas** that allows for students to develop a plan of study that supports their interests. While Dartmouth's AB degree program employs a systems approach to allow for students to draw from multiple areas of expertise, undergraduate engineering majors may choose specialized coursework from:

- Biological and Chemical Engineering
- Biomedical Engineering
- Electrical and Computer Engineering
- Energy Engineering
- Materials Science and Engineering
- Mechanical, Operations and Systems Engineering

Culminating Experience

All majors and modified majors are also required to complete a culminating experience, in addition to required coursework. Normally completed during the senior year, the culminating experience may include an honors thesis, an independent project, the two-course engineering design capstone series (ENGS 89/90), or an advanced course with significant design or research project, chosen from an approved list. Visit each page for the major or modified major for more detailed requirements.

Honors Program

engineering.dartmouth.edu/undergraduate/honors

AB students with 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.

Honors in Engineering Sciences

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.

High Honors in Engineering Sciences

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 is eligible to receive a degree with High Honors in Engineering Sciences. A vote of the faculty in the Department of Engineering Sciences is required prior to awarding High Honors.

Grade Standards for the AB

engineering.dartmouth.edu/courses/grading#grading-for-ab-and-be-candidates

Courses for the AB are assigned grades ranging from A (for distinctly superior work) to E (unacceptable for degree credit). “Plus (+)” or “Minus (-)” following a grade indicates that, in the opinion of the instructor, the student has performed at a level slightly higher or lower than the norm for the category.

GRADE	STANDARDS	GRADE POINT VALUES
A	Distinctly superior work	**A** = 4.0; **A-** = 3.67
B	Good work	**B+** = 3.33; **B** = 3.00; **B-** = 2.67
C	Acceptable mastery of course material	**C+** = 2.33; **C** = 2.00; **C-** = 1.67
D	Deficient in mastery of course material	**D** = 1.00
E	Serious deficiency in mastery of course material	**E** = 0.00

Minimum GPA Requirements

AB candidates must:

- Maintain a minimum grade point average of 2.00 in the courses required for majors in Engineering Sciences, Engineering Physics, Biomedical Engineering, and all modified majors; and/or
- Maintain a minimum grade point average of 2.00 in the courses required for the minor in Engineering Sciences, Human-Centered Design, or Materials Science.

Additional details about Academic Regulations and Actions can be found in Dartmouth’s Students Affairs website: student-affairs.dartmouth.edu/policy/academic-regulations-and-actions.

Residency Requirements

Students who are registered and enrolled in two or more courses a term are considered full-time and as being “in residence.” AB candidates should refer to Dartmouth’s Organization, Regulations, and Courses for residency requirements (dartmouth.smartcatalogiq.com/current/orc).

Engineering as a Foundation for Professional Fields

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

PROFESSIONAL FIELD	POSSIBLE MAJORS
Architecture	Engineering Sciences major modified with Studio Art
Biomedical engineering	Biomedical Engineering Sciences major
Biotechnology	Engineering Sciences major modified with Biology
Chemical engineering	Engineering Sciences major modified with Chemistry
Computer engineering	Engineering Sciences major modified with Computer Science
Environmental engineering	Engineering Sciences major modified with Environmental Sciences
Engineering (general) *or* other interdisciplinary field	Engineering Sciences major
Engineering Physics	Engineering Physics major
Geology or Geotechnology	Engineering Sciences major modified with Earth Sciences
Human-Centered Design	Human-Centered Design minor *or* Other Major modified with Human-Centered Design
Management and Finance	Engineering Sciences major modified with Economics
Materials science	Materials Science minor with Chemistry or Physics major
Medicine	Biomedical Engineering Sciences major
Neuroscience or neurotechnology	Engineering Sciences major modified with Neuroscience
Product Design	Engineering Sciences major modified with Studio Art
Technology in Public Policy	Engineering Sciences modified with Public Policy

ENGINEERING SCIENCES MAJOR

The undergraduate major in Engineering Sciences leads to a Bachelor of Arts (AB), a liberal arts degree awarded by Dartmouth College. Students who plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Douglas Van Citters**, Chair of the Department of Engineering Sciences and Associate Dean for Undergraduate Education.

PREREQUISITES			
Mathematics		MATH 3 Calculus	3 courses
		MATH 8 Calculus of Functions of One and Several Variables	
		MATH 11 Accelerated Multivariable Calculus or MATH 13 Calculus of Vector-Valued Functions	
Physics		PHYS 13 Introductory Physics I and PHYS 14 Introductory Physics II	2 courses
Chemistry		CHEM 5 General Chemistry	1 course
Computer Science **(Choose 1)**		ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)	1 or 2 courses
		COSC 1 Introduction to Programming and Computation and COSC 10 Problem Solving via Object-Oriented Programming	
REQUIRED COURSES			
Common Core Courses		ENGS 21 Introduction to Engineering (Should be taken sophomore year.)	3 courses
		ENGS 22 Systems	
		ENGS 23 Distributed Systems and Fields	
Distributive Core Courses **(Choose 2)**		ENGS 24 Science of Materials	2 courses
		ENGS 25 Introduction to Thermodynamics	
		ENGS 26 Control Theory	
		ENGS 27 Discrete and Probabilistic Systems	
		ENGS 28 Embedded Systems	
Gateway Courses **(Choose 2, each from a different discipline)**	Electrical	ENGS 31 Digital Electronics	2 courses
		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 Engineering Sciences or one from each option)**	Engineering Sciences	Any ENGS course numbered 20 and above (excluding ENGS 80 and 87)	2 courses
	Science/Math	ASTR 15 and above; BIOL 12 and above (excluding BIOL 52); CHEM 6, 10 and above (excluding CHEM 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 and above; COSC 30, 31, 39, 49, 71, 74	

Engineering Sciences major (continued on next page)

Culminating Experience for Majors and Modified Majors

In addition to coursework, all majors and modified majors are required to complete a culminating experience, which may include a thesis, a design project, or advanced Engineering Sciences course with a significant design or research project, chosen from an approved list. The advanced engineering course for the culminating experience may be taken as one of the required electives or as an additional course.

<table>
<tr><th colspan="3">CULMINATING EXPERIENCE</th></tr>
<tr><td rowspan="3">Culminating Experience
(Choose 1)</td><td>Thesis</td><td>ENGS 86 Independent Project or
ENGS 88 Honors Thesis</td></tr>
<tr><td>Design Project</td><td>ENGS 89 Engineering Design Methodology and Project Initiation and
ENGS 90 Engineering Design Methodology and Project Completion
● Taken as a two-course design sequence.
● May count toward both AB and BE degrees.
● 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.</td></tr>
<tr><td>Advanced Course
(Choose 1)</td><td>One advanced Engineering Sciences course with a significant design or research project. Students should consult the approved list of courses on Thayer’s website (engineering.dartmouth.edu/undergraduate/ab/majors/engineering-sciences) or with the Chair of the Department of Engineering Sciences.</td></tr>
</table>

BIOMEDICAL ENGINEERING SCIENCES MAJOR

The Biomedical Engineering Sciences major is aimed at students interested in pursuing medical school following their undergraduate studies. Faculty from Thayer School of Engineering and Geisel School of Medicine jointly advise research. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professors Brian Pogue** or **Douglas Van Citters**.

PREREQUISITES			
Mathematics	MATH 3 Calculus		3 courses
	MATH 8 Calculus of One and Several Variables		
	MATH 11 Accelerated Multivariable Calculus or MATH 13 Calculus of Vector-Valued Functions		
Chemistry **(Choose 1 option)**	CHEM 5 and CHEM 6 General Chemistry		1 or 2 courses
	CHEM 10 Honors First-Year Chemistry		
Physics	PHYS 13 Introductory Physics I and PHYS 14 Introductory Physics II		2 courses
Computer Science **(Choose 1 option)**	ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)		1 or 2 courses
	COSC 1 Introduction to Programming and Computation and COSC 10 Problem Solving via Object-Oriented Programming		
REQUIRED COURSES			
Common Core Courses	ENGS 21 Introduction to Engineering (Should be taken sophomore year.)		2 courses
	ENGS 22 Systems		
Common and Distributive Core Courses **(Choose 1)**	ENGS 23 Distributed Systems and Fields		1 course
	ENGS 24 Science of Materials		
	ENGS 25 Introduction to Thermodynamics		
	ENGS 26 Control Theory		
	ENGS 27 Discrete and Probabilistic Systems		
Gateway Course **(Choose 1)**	Electrical	ENGS 31 Digital Electronics	1 course
		ENGS 32 Electronics: Introduction to Linear and Digital Circuits	
	Mechanical	ENGS 33 Solid Mechanics	
		ENGS 34 Fluid Dynamics	
	Chemical/ Biochemical	ENGS 35 Biotechnology and Biochemical Engineering	
		ENGS 36 Chemical Engineering	
Engineering Course	ENGS 56 Biomedical Engineering or 1 additional course from ENGS 23–26		1 course
Biology Courses **(Choose 2)**	BIOL 12 Cell Structure and Function		2 courses
	BIOL 13 Gene Expression and Inheritance		
	BIOL 14 Physiology		
Chemistry Courses **(Choose 2)**	CHEM 51 and 52 Organic Chemistry or CHEM 57 and 58 Organic Chemistry		2 courses
Elective* **(Choose 1)**	Engineering Sciences course numbered above ENGS 23		1 course
	BIOL 40 Biochemistry		
	CHEM 41 Biological Chemistry		

Biomedical Engineering Sciences major (continued on next page)

Biomedical Engineering Sciences major (continued from previous page)

CULMINATING EXPERIENCE		
Culminating Experience** **(Choose 1 option)**	Thesis	ENGS 86 Independent Project or ENGS 88 Honors Thesis
	Advanced Course **(Choose 1)**	ENGS 160 Biotechnology and Biochemical Engineering
		ENGS 161 Metabolic Engineering
		ENGS 162 Methods in Biotechnology
		ENGS 163 Advanced Protein Engineering
		ENGS 165 Biomaterials
		ENGS 167 Medical Imaging
		ENGS 169 Intermediate Biomedical Engineering

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

Geisel Biomedical Engineering Early Assurance Program (BME EAP)

Highly qualified Biomedical Engineering Sciences and Engineering Sciences majors planning to pursue medical school following their undergraduate studies may be invited to apply for early admission to the Geisel School of Medicine at Dartmouth through the Geisel Biomedical Engineering Early Assurance Program (BME EAP).

The Geisel Biomedical Engineering Early Assurance Program is a separate program from the Geisel Early Assurance program for Dartmouth juniors. Students may only apply to one Geisel early assurance program and are strongly advised to apply through Thayer School of Engineering via the BME EAP. Interested students should consult with their faculty advisors.

ENGINEERING PHYSICS MAJOR

The Department of Engineering Sciences and the Department of Physics and Astronomy jointly offer a major in Engineering Physics. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Jifeng Liu** (Engineering) or **Professor Kristina Lynch** (Physics and Astronomy).

<table>
<tr><th colspan="4">PREREQUISITES</th></tr>
<tr><td rowspan="4">Mathematics</td><td colspan="2">MATH 3 Calculus</td><td rowspan="4">4 courses</td></tr>
<tr><td colspan="2">MATH 8 Calculus of Functions of One and Several Variables</td></tr>
<tr><td colspan="2">MATH 13 Calculus of Vector-Valued Functions</td></tr>
<tr><td colspan="2">MATH 23 Differential Equations</td></tr>
<tr><td>Physics</td><td colspan="2">PHYS 13 Introductory Physics I and PHYS 14 Introductory Physics II</td><td>2 courses</td></tr>
<tr><td>Chemistry</td><td colspan="2">CHEM 5 General Chemistry</td><td>1 course</td></tr>
<tr><td rowspan="2">Computer Science
(Choose 1 option)</td><td colspan="2">ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)</td><td rowspan="2">1 or 2 courses</td></tr>
<tr><td colspan="2">COSC 1 Introduction to Programming and Computation and
COSC 10 Problem Solving via Object-Oriented Programming</td></tr>
<tr><th colspan="4">REQUIRED COURSES*</th></tr>
<tr><td rowspan="3">Engineering Core Courses</td><td colspan="2">ENGS 22 Systems</td><td rowspan="3">3 courses</td></tr>
<tr><td colspan="2">ENGS 23 Distributed Systems and Fields</td></tr>
<tr><td colspan="2">ENGS 24 Science of Materials</td></tr>
<tr><td rowspan="3">Physics Core Courses**</td><td colspan="2">PHYS 19 Introductory Physics III</td><td rowspan="3">3 courses</td></tr>
<tr><td colspan="2">PHYS 40 Quantum Physics of Matter: An Introduction</td></tr>
<tr><td colspan="2">PHYS 43 Statistical Physics</td></tr>
<tr><td rowspan="13">Electives**
(Choose 2 courses, each from a different group)</td><td rowspan="3">Group 1</td><td>ENGS 25 Introduction to Thermodynamics</td><td rowspan="13">2 courses</td></tr>
<tr><td>ENGS 33 Solid Mechanics</td></tr>
<tr><td>ENGS 34 Fluid Dynamics</td></tr>
<tr><td rowspan="3">Group 2</td><td>PHYS 50 Introductory Quantum Mechanics</td></tr>
<tr><td>PHYS 68 Introductory Plasma Physics</td></tr>
<tr><td>PHYS 91 Intermediate Quantum Mechanics</td></tr>
<tr><td rowspan="2">Group 3</td><td>PHYS 73 Introductory Condensed Matter Physics</td></tr>
<tr><td>ENGS 131 Science of Solid State Materials</td></tr>
<tr><td rowspan="2">Group 4</td><td>PHYS 66 Relativistic Electrodynamics</td></tr>
<tr><td>ENGS 64 Engineering Electromagnetics or
ENGS 120 Electromagnetic Waves</td></tr>
<tr><td rowspan="2">Group 5</td><td>PHYS 44 Mechanics</td></tr>
<tr><td>ENGS 72 Applied Mechanics: Dynamics</td></tr>
<tr><td></td></tr>
<tr><td>Free electives***
(Choose 2)</td><td colspan="2">Any ENGS courses numbered 20 and above (excluding ENGS 80 and 87) or any PHYS course that fulfills the straight Physics major.</td><td>2 courses</td></tr>
</table>

Engineering Physics major (continued on next page)

Engineering Physics major (continued on next page)

CULMINATING EXPERIENCE		
Culminating Experience **(Choose 1 option)**	Thesis	ENGS 86 Independent Project or ENGS 88 Honors Thesis
	Design Project	ENGS 89 Engineering Design Methodology and Project Initiation and ENGS 90 Engineering Design Methodology and Project Completion ● Taken as a two-course design sequence. ● May count toward both AB and BE degrees. ● 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.
	Advanced Course **(Choose 1)**	One advanced Engineering Sciences course with a significant design or research project. Students should consult the approved list of courses on Thayer's website (engineering.dartmouth.edu/undergraduate/ab/majors/engineering-sciences) or with the Chair of the Department of Engineering Sciences.
		PHYS 68 Introductory Plasma Physics
		PHYS 72 Introductory Particle Physics
		PHYS 73 Introductory Condensed Matter Physics
		PHYS 74 Space Plasma Physics
		PHYS 76 Methods of Experimental Physics
		PHYS 82 Special Topics Seminar
		PHYS 87 Undergraduate Research

* 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 taking the honors sequence, PHYS 15 and 16, should substitute a third Physics elective for PHYS 19.
*** Students wishing to pursue the BE degree are advised to choose an Engineering Sciences course as their elective.

ENGINEERING SCIENCES MAJOR MODIFIED WITH BIOLOGY

Students interested in biotechnology, engineering, and biology may elect an Engineering Sciences major modified with biology. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Lee R. Lynd**.

PREREQUISITES		
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II	2 courses
Chemistry (Choose 1)	CHEM 5 General Chemistry	1 course
	CHEM 10 Honors First-Year General Chemistry	
Computer Science (Choose 1 option)	ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)	1 or 2 courses
	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	ENGS 22 Systems	3 courses
	ENGS 25 Introduction to Thermodynamics	
	ENGS 35 Biotechnology and Biochemical Engineering	
Engineering Electives (Choose 3)	ENGS 21 Introduction to Engineering (Should be taken sophomore year.)	3 courses
	ENGS 23 Distributed Systems and Fields	
	ENGS 24 Science of Materials	
	ENGS 26 Control Theory	
	ENGS 33 Solid Mechanics	
	ENGS 34 Fluid Dynamics	
	ENGS 36 Chemical Engineering	
	ENGS 37 Introduction to Environmental Engineering	
	ENGS 52 Introduction to Operations Research	
	ENGS 56 Introduction to Biomedical Engineering	
	ENGS 58 Introduction to Protein Engineering	
	ENGS 91 Numerical Methods in Computation	
	ENGS 161 Metabolic Engineering	
	ENGS 162 Methods in Biotechnology	
	ENGS 165 Biomaterials	
Biology Core Course	BIOL 13 Gene Expression and Inheritance	1 course

Engineering Sciences major modified with Biology (continued on next page)

Engineering Sciences major modified with Biology (continued from previous page)

REQUIRED COURSES (continued)		
Biology or Chemistry Electives (Choose 3)	BIOL 37 Endocrinology	3 courses
	BIOL 42 Biology of the Immune Response	
	BIOL 43 Developmental Biology	
	BIOL 45 Molecular Biology	
	BIOL 46 Microbiology	
	BIOL 71 Current Topics in Cell Biology	
	CHEM 51 Organic Chemistry or CHEM 57 Honors Organic Chemistry	
CULMINATING EXPERIENCE		
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)	

ENGINEERING SCIENCES MAJOR MODIFIED WITH CHEMISTRY

Students interested in chemical engineering may elect an Engineering Sciences major modified with Chemistry. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Lee R. Lynd**.

PREREQUISITES		
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II	2 courses
Chemistry	CHEM 5-6 General Chemistry or CHEM 10 Honors First-Year General Chemistry	1 course
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)	1 or 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 25 Introduction to Thermodynamics	
	ENGS 36 Chemical Engineering	
Engineering Electives (Choose 3. No more than two courses from ENGS 21, 35, or 37 may count towards the major.)	ENGS 21 Introduction to Engineering (Should be taken sophomore year.)	3 courses
	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	
Chemistry Core Courses	CHEM 51 Organic Chemistry or CHEM 57 Honors Organic Chemistry	2 courses
	CHEM 75 Physical Chemistry I	
Chemistry Electives (choose 2)	CHEM 41 Biological Chemistry I	2 courses
	CHEM 52 Organic Chemistry or CHEM 58 Honors Organic Chemistry	
	CHEM 63 Environmental Chemistry	
	CHEM 64 Basic Inorganic Chemistry	
	CHEM 67 Physical Biochemistry I	
	CHEM 76 Physical Chemistry II	
CULMINATING EXPERIENCE		
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)	

ENGINEERING SCIENCES MAJOR MODIFIED WITH COMPUTER SCIENCE

Students interested in computer engineering may pursue the Engineering Sciences major modified with Computer Science. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professors Eugene Santos** or **Stephen Taylor**.

PREREQUISITES			
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II		2 courses
Chemistry	CHEM 5 General Chemistry		1 course
Computer Science	COSC 1 Introduction to Programming and Computation or ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)		2 courses
	COSC 10 Problem Solving via Object-Oriented Programming		
REQUIRED COURSES			
Engineering Core Courses	Group 1 **(All 3 courses required)**	ENGS 22 Systems	4 courses
		ENGS 27 Discrete and Probabilistic Systems	
		ENGS 31 Digital Electronics	
	Group 2 **(Choose 1)**	ENGS 23 Distributed Systems and Fields	
		ENGS 24 Science of Materials	
Computer Science Course	COSC 50 or ENGS 50 Software Design and Implementation		1 course
Breadth Requirements **(Choose 5 courses, including at least 1 course from each group. At least 3 courses must be from Computer Science.)**	Group 1	ENGS 32 Electronics: Introduction to Linear and Digital Circuits	5 courses
		ENGS 62 Microprocessors in Engineered Systems	
		COSC 51 Computer Architecture	
	Group 2	ENGS 26 Control Theory	
		ENGS 68 Introduction to Communications Systems	
		ENGS 92 Fourier Transforms and Complex Variables	
		COSC 60 Computer Networks	
	Group 3	ENGS 91 Numerical Methods in Computation	
		COSC 31 Algorithms	
		COSC 58 Operating Systems	
		COSC 77 Computer Graphics	
CULMINATING EXPERIENCE			
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)		

ENGINEERING SCIENCES MAJOR MODIFIED WITH EARTH SCIENCES

Students interested in geotechnical engineering may pursue the Engineering Sciences major modified with Earth Sciences. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Erland Schulson**.

PREREQUISITES		
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II	2 courses
Chemistry	CHEM 5 General Chemistry	1 course
Computer Science (Choose 1 option)	ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)	1 course
	COSC 1 Introduction to Programming and Computation and COSC 10 Problem Solving via Object-Oriented Programming	
Earth Sciences	One introductory Earth Sciences course from EARS 1-9 (excluding EARS 7)	2 courses
	EARS 40 Materials of the Earth	
REQUIRED COURSES		
Engineering Sciences	ENGS 22 Systems	6 courses
	ENGS 23 Distributed Systems and Fields	
	ENGS 24 Science of Materials	
	ENGS 25 Introduction to Thermodynamics	
	Two Engineering Sciences electives numbered above 20 (excluding 80 and 87)	
Earth Sciences	Four EARS courses numbered 10 or above, at least one of which must be a Core Methods and Concepts course (Earth Sciences 30-59) and at least one of which must be a Quantitative Analysis or Advanced Topics course (Earth Sciences 60-79)	4 courses
CULMINATING EXPERIENCE		
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)	

ENGINEERING SCIENCES MAJOR MODIFIED WITH ECONOMICS

Students interested in management and finance may pursue the Engineering Sciences major modified with Economics. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Geoffrey Parker**.

<table>
<tr><th colspan="4">PREREQUISITES</th></tr>
<tr><td rowspan="3">Mathematics</td><td colspan="2">MATH 3 Calculus</td><td rowspan="3">3 courses</td></tr>
<tr><td colspan="2">MATH 8 Calculus of Functions of One and Several Variables</td></tr>
<tr><td colspan="2">MATH 13 Calculus of Vector-Valued Functions</td></tr>
<tr><td>Physics</td><td colspan="2">PHYS 13 Introductory Physics I and
PHYS 14 Introductory Physics II</td><td>2 courses</td></tr>
<tr><td>Chemistry</td><td colspan="2">CHEM 5 General Chemistry</td><td>1 course</td></tr>
<tr><td rowspan="2">Computer Science
(Choose 1 option)</td><td colspan="2">ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)</td><td rowspan="2">1 or 2 courses</td></tr>
<tr><td colspan="2">COSC 1 Introduction to Programming and Computation and
COSC 10 Problem Solving via Object-Oriented Programming</td></tr>
<tr><td rowspan="2">Economics</td><td colspan="2">ECON 1 The Price System: Analysis, Problems, and Policies</td><td rowspan="2">2 courses</td></tr>
<tr><td colspan="2">ECON 10 Introduction to Statistical Methods</td></tr>
<tr><th colspan="4">REQUIRED COURSES</th></tr>
<tr><td rowspan="3">Engineering Core Courses</td><td colspan="2">ENGS 21 Introduction to Engineering (Should be taken sophomore year.)</td><td rowspan="3">3 courses</td></tr>
<tr><td colspan="2">ENGS 22 Systems</td></tr>
<tr><td colspan="2">ENGS 52 Introduction to Operations Research (Prerequisite is Math 22.)</td></tr>
<tr><td rowspan="5">Engineering Electives</td><td rowspan="4">Group A
(Choose 1)</td><td>ENGS 23 Distributed Systems and Fields</td><td rowspan="5">3 courses</td></tr>
<tr><td>ENGS 24 Science of Materials</td></tr>
<tr><td>ENGS 25 Introduction to Thermodynamics</td></tr>
<tr><td>ENGS 33 Solid Mechanics</td></tr>
<tr><td>Group B
(Choose 2)</td><td>Choose from any other Engineering Sciences course that counts toward the AB degree program.</td></tr>
<tr><td rowspan="3">Economics Courses
(Choose 2)</td><td colspan="2">ECON 20 Econometrics</td><td rowspan="3">2 courses</td></tr>
<tr><td colspan="2">ECON 21 Microeconomics</td></tr>
<tr><td colspan="2">ECON 22 Macroeconomics</td></tr>
<tr><td rowspan="6">Economics Electives
(Choose a 2-course sequence from one of the groups)</td><td rowspan="2">Money and Finance</td><td>ECON 26 The Economics of Financial Intermediaries and Markets</td><td rowspan="6">2 courses</td></tr>
<tr><td>ECON 36 Theory of Finance</td></tr>
<tr><td rowspan="2">Industrial Organization</td><td>ECON 25 Industrial Organization and Public Policy</td></tr>
<tr><td>ECON 35 Games and Economic Behavior or
ECON 45 Topics in Industrial Organization</td></tr>
<tr><td rowspan="2">International Trade</td><td>ECON 29 International Finance and Open- Economy Macroeconomics</td></tr>
<tr><td>ECON 39 International Trade</td></tr>
<tr><th colspan="4">CULMINATING EXPERIENCE</th></tr>
<tr><td>Culminating Experience</td><td colspan="3">Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)</td></tr>
</table>

ENGINEERING SCIENCES MAJOR MODIFIED WITH ENVIRONMENTAL SCIENCES

Students interested in environmental engineering may pursue the Engineering Sciences major modified with Environmental Sciences. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professors Benoit Cushman-Roisin** or **Lee Lynd.**

PREREQUISITES			
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II		2 courses
Chemistry (Choose 1)	CHEM 5 General Chemistry		1 course
	CHEM 10 Honors First-Year General Chemistry		
Computer Science (Choose 1 option)	ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)		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	ENGS 22 Systems		3 courses
	ENGS 25 Introduction to Thermodynamics		
	ENGS 37 Introduction to Environmental Engineering		
Engineering Electives (Choose 3. At least 2 of the courses must be from Group A)	Group A	ENGS 41 Sustainability and Natural Resource Management	3 courses
		ENGS 43 Environmental Transport and Fate	
		ENGS 44 Sustainable Design	
	Group B	ENGS 27 Discrete and Probabilistic Systems	
		ENGS 34 Fluid Mechanics	
		ENGS 35 Biotechnology and Biochemical Engineering	
		ENGS 36 Chemical Engineering	
		ENGS 52 Introduction to Operations Research	
		ENGS 171 Industrial Ecology	
		ENGS 172 Climate Change and Engineering	
Environmental Sciences Electives (Choose 4. At least 2 courses must be from a single department.) (continued)	Biology	BIOL 21 Population Ecology or BIOL 51 Advanced Population Ecology	4 courses (continued)
		BIOL 22 Methods in Ecology	
		BIOL 25 Introductory Marine Biology and Ecology	
		BIOl 26 Global Change Biology	
		BIOL 27 Animal Behavior	
		BIOL 53 Aquatic Ecology	
	Chemistry	CHEM 51 Organic Chemistry (only as prerequisite to CHEM 63)	
		CHEM 63 Environmental Chemistry	

Engineering Sciences major modified with Environmental Sciences (continued on next page)

Engineering Sciences major modified with Environmental Sciences (continued from previous page)

REQUIRED COURSES (continued)			
(continued) **Environmental Sciences Electives** **(Choose 4. At least 2 courses must be from a single department.)**	Earth Sciences	EARS 16 Hydrology and Water Resources	(continued) 4 courses
		EARS 35 The Soil Resource	
		EARS 66 Hydrogeology	
		EARS 71 River Processes and Watershed Science	
		EARS 76 Advanced Hydrology	
		EARS 77 Environmental Applications of GIS	
		EARS 78 Climate Dynamics	
	Environmental Studies	ENVS 12 Energy and the Environment	
		ENVS 15 Environmental issues of Earth's Cold Regions	
		ENVS 20 Conservation of Biodiversity	
		ENVS 25 Agroecology	
		ENVS 30 Global Environmental Science	
CULMINATING EXPERIENCE			
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)		

ENGINEERING SCIENCES MAJOR MODIFIED WITH NEUROSCIENCE

Students interested in environmental engineering may pursue the Engineering Sciences major modified with Environmental Sciences. Students who also plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Laura Ray.**

PREREQUISITES		
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II	2 courses
Chemistry	CHEM 5-6 General Chemistry or CHEM 10 Honors First-Year General Chemistry	1 course
Computer Science **(choose 1 option)**	ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)	1 or 2 courses
	COSC 1 Introduction to Programming and Computation and COSC 10 Problem Solving via Object-Oriented Programming	
Neuroscience	PSYC 6 Introduction to Neuroscience	1 course
REQUIRED COURSES		
Engineering Core Courses	ENGS 21 Introduction to Engineering (Should be taken sophomore year.)	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	
Engineering Electives **(Choose 2)**	ENGS 26 Control Theory (if not taken above)	2 courses
	ENGS 27 Discrete and Probabilistic Systems (if not taken above)	
	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	
Neuroscience Core Courses **(Choose 2)**	PSYC 35 Cellular and Molecular Neuroscience	2 courses
	PSYC 36 Systems Neuroscience with Laboratory	
	PSYC 37 Behavioral Neuroscience	

Engineering Sciences major modified with Neuroscience (continued on next page)

Engineering Sciences major modified with Neuroscience (continued from previous page)

REQUIRED COURSES (continued)		
Neuroscience Electives (Choose 2)	PSYC 21 Perception	2 courses
	PSYC 38 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 (Only one seminar allowed as one of the two electives.)	
CULMINATING EXPERIENCE		
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)	

ENGINEERING SCIENCES MAJOR MODIFIED WITH PUBLIC POLICY

Students interested in technology and public policy may pursue the Engineering Sciences major modified with Public Policy. Students who plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Dean and Professor of Engineering Alexis Abramson**.

<table>
<tr><th colspan="4">PREREQUISITES</th></tr>
<tr><td rowspan="3">Mathematics</td><td colspan="2">MATH 3 Calculus</td><td rowspan="3">3 courses</td></tr>
<tr><td colspan="2">MATH 8 Calculus of Functions of One and Several Variables</td></tr>
<tr><td colspan="2">MATH 13 Calculus of Vector-Valued Functions</td></tr>
<tr><td>Physics</td><td colspan="2">PHYS 13 Introductory Physics I and
PHYS 14 Introductory Physics II</td><td>2 courses</td></tr>
<tr><td>Chemistry</td><td colspan="2">CHEM 5 General Chemistry</td><td>1 course</td></tr>
<tr><td rowspan="2">Computer Science
(Choose 1 option)</td><td colspan="2">ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)</td><td rowspan="2">1 or 2 courses</td></tr>
<tr><td colspan="2">COSC 1 Introduction to Programming and Computation and
COSC 10 Problem Solving via Object-Oriented Programming</td></tr>
<tr><td rowspan="4">Statistical Data Analysis
(Choose 1)</td><td colspan="2">ECON 10 Introduction to Statistical Methods</td><td rowspan="4">1 course</td></tr>
<tr><td colspan="2">GOVT 10 Quantitative Political Analysis</td></tr>
<tr><td colspan="2">SOCY 10 Quantitative Analysis of Social Data</td></tr>
<tr><td colspan="2">MATH 10 Introductory Statistics</td></tr>
<tr><th colspan="4">REQUIRED COURSES</th></tr>
<tr><td rowspan="2">Engineering Core Courses</td><td colspan="2">ENGS 21 Introduction to Engineering (Should be taken sophomore year.)</td><td rowspan="2">2 courses</td></tr>
<tr><td colspan="2">ENGS 22 Systems</td></tr>
<tr><td rowspan="18">Engineering Electives (Choose 4, with one course from each group.)

(continued)</td><td rowspan="5">Group 1
(Choose 1)</td><td>ENGS 23 Distributed Systems and Fields</td><td rowspan="18">4 courses

(continued)</td></tr>
<tr><td>ENGS 24 Science of Materials</td></tr>
<tr><td>ENGS 25 Introduction to Thermodynamics</td></tr>
<tr><td>ENGS 26 Control Theory</td></tr>
<tr><td>ENGS 27 Discrete and Probabilistic Systems</td></tr>
<tr><td rowspan="8">Group 2
(Choose 1)</td><td>ENGS 30 Biological Physics</td></tr>
<tr><td>ENGS 31 Digital Electronics</td></tr>
<tr><td>ENGS 32 Electronics: Introduction to Linear and Digital Circuits</td></tr>
<tr><td>ENGS 33 Solid Mechanics</td></tr>
<tr><td>ENGS 34 Fluid Dynamics</td></tr>
<tr><td>ENGS 35 Biotechnology and Biochemical Engineering</td></tr>
<tr><td>ENGS 36 Chemical Engineering</td></tr>
<tr><td>ENGS 37 Introduction to Environmental Engineering</td></tr>
<tr><td rowspan="5">Group 3
(Choose 1)</td><td>ENGS 41 Sustainability and Natural Resources Management</td></tr>
<tr><td>ENGS 43 Environmental Transport and Fate</td></tr>
<tr><td>ENGS 44 Sustainable Design</td></tr>
<tr><td>ENGS 52 Introduction to Operations Research</td></tr>
<tr><td>ENGS 56 Introduction to Biomedical Engineering</td></tr>
</table>

Engineering Sciences major modified with Public Policy (continued on next page)

Engineering Sciences major modified with Public Policy (continued from previous page)

REQUIRED COURSES (continued)			
(continued) **Engineering Electives**	Group 4 **(Choose 1)**	Any ENGS course numbered above 20 (excluding ENGS 80 and 87)	(continued) 4 courses
Public Policy **(Choose 4 with at least one course from each group)**	Group 1	PBPL 5 Introduction to Public Policy	4 courses
	Group 2	PBPL 40 Economics of Public Policy Making	
		PBPL 41 Writing and Speaking Public Policy	
		PBPL 42 Ethics and Public Policy	
		PBPL 43 Social Entrepreneurship	
		PBPL 45 Introduction to Public Policy Research	
		PBPL 46 Policy Implementation	
		ECON 20 Econometrics	
	Group 3	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			
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)		

ENGINEERING SCIENCES MAJOR MODIFIED WITH STUDIO ART

Students interested in architecture or product design may pursue the Engineering major modified with Studio Art. Students who plan to pursue additional coursework beyond the AB to earn the Bachelor of Engineering (BE) should consult early with their faculty advisors to plan their program of study.

For advice about the major, contact **Professor Peter Robbie**.

PREREQUISITES		
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II	2 courses
Chemistry	CHEM 5 General Chemistry	1 course
Computer Science **(Choose 1 option)**	ENGS 20 Introduction to Scientific Computing (May not be taken under Non-Recording Option.)	1 or 2 course
	COSC 1 Introduction to Programming and Computation and COSC 10 Problem Solving via Object-Oriented Programming	
REQUIRED COURSES		
Engineering Core Courses	ENGS 21 Introduction to Engineering (Should be taken sophomore year.)	4 courses
	ENGS 22 Systems	
	ENGS 24 Science of Materials	
	ENGS 33 Solid Mechanics	
Engineering Electives	Any two Engineering Sciences courses required for AB credit in the major.	2 courses
Studio Art Core Courses	SART 15 Drawing I	2 courses
	SART 16 Sculpture I	
Studio Art Electives	Any upper level Studio Art courses	2 courses
CULMINATING EXPERIENCE		
Culminating Experience	Thesis, design project, or advanced course (See page 23 for detailed requirements for modified majors.)	

* ENGS 76 or a graduate level elective also satisfies the culminating experience requirement.

ENGINEERING SCIENCES MINOR

Students can complement a major in another discipline with a minor in Engineering Sciences. Please 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. Courses used in the major cannot be used to satisfy requirements of the minor.

For advice about the minor, contact **Professor Douglas Van Citters**, Chair of the Department of Engineering Sciences and Associate Dean for Undergraduate Education.

	PREREQUISITES	
Mathematics	MATH 3 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 and PHYS 14 Introductory Physics II	2 courses
	REQUIRED COURSES	
Core Courses	ENGS 20 Introduction to Scientific Computing or COSC 1 Introduction to Programming and Computation and COSC 10 Problem Solving via Object-Oriented Programming	3 courses
	ENGS 21 Introduction to Engineering (Should be taken sophomore year.)	
	ENGS 22 Systems	
Electives **(Choose 2)**	Any ENGS course numbered above 20 (excluding ENGS 80 and 87)	2 courses

HUMAN-CENTERED DESIGN MINOR

The minor in Human-Centered Design is an interdisciplinary program focused on the process of innovation for addressing human needs. The six-course minor combines engineering and design thinking courses with a wide range of cultural, behavioral, and artistic offerings. 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. Courses used in the major cannot be used to satisfy requirements of the minor.

For advice about the minor, contact **Professor Peter Robbie** (Engineering) or **Professor Lori Loeb** (Computer Science).

PREREQUISITES		
Mathematics	MATH 3 Calculus	1 course
REQUIRED COURSES*		
Design Foundation	ENGS 12 Design Thinking	2 courses
	ENGS 21 Introduction to Engineering (Should be taken after ENGS 12 and before Design Electives.)	
Ethnographic Methods and Human Factors/ Psychology**	ANTH 3 Intro to Cultural Anthropology	2 courses
	ANTH 18 Intro to Research Methods in Cultural Anthropology	
	GEOG 11 Qualitative Methods and the Research Process in Geography	
	SOCY 11 Research Methods	
	PSYC 22 Learning	
	PSYC 23 Social Psychology	
	PSYC 28 Cognitive Psychology	
	PSYC 38 Cognitive Neuroscience	
	PSYC 43 Emotion	
	PSYC 50.02 Decision Making	
	PSYC 53.10 Social and Affective Motivations in Decision-Making	
	PSYC 53.12 The Behavior of Groups	
	PSYC 53.13 Social Neuroscience	
Design Electives*** (continued)	ENGS 15.01 Senior Design Challenge	2 courses (continued)
	ENGS 15.02 Senior Design Challenge	
	ENGS 18 Systems Dynamics in Policy Design and Analysis	
	ENGS 44 Sustainable Design	
	ENGS 75 Product Design	
	COSC 23.01 Augmented and Virtual Reality Design	
	COSC 25.01 UI/UX Design I	
	COSC 25.02 UI/UX Design II	
	COSC 28 Advanced Projects in Digital Arts	
	COSC 29.04/PBS 15 Impact Design	
	FILM 51 Game Design	
	PBPL 43/ECON 77 Social Entrepreneurship	

Human-Centered Design minor (continued on next page)

Human-Centered Design minor (continued from previous page)

REQUIRED COURSES* (continued)		
(continued) **Design Electives*****	SART 65 Architecture I	(continued) 2 courses
	SART 66 Architecture II	
	SART 68 Architecture III	
	Independent study in a relevant discipline	

* For Engineering Sciences majors, only ENGS courses numbers 20 or below may count toward the minor.
** One of the two courses under Ethnographic Methods and Human Factors must be outside of the student's major department.
*** Before taking courses under Design Electives, it is recommended that students complete both courses under Design Foundation and at least one course under Ethnographic Methods and Human Factors/Psychology. No Engineering Sciences courses 20 and above may be taken under the Non-Recording Option.

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. Please 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. Courses used in the major cannot be used to satisfy requirements of the minor.

For advice about the minor, contact **Professor Douglas Van Citters**, Chair of the Department of Engineering Sciences and Associate Dean for Undergraduate Education.

<table>
<tr><th colspan="4">PREREQUISITES</th></tr>
<tr><td>Chemistry</td><td colspan="2">CHEM 5 and CHEM 6 General Chemistry</td><td>2 courses</td></tr>
<tr><td>Physics</td><td colspan="2">PHYS 13 Introductory Physics I and PHYS 14 Introductory Physics II</td><td>2 courses</td></tr>
<tr><th colspan="4">REQUIRED COURSES</th></tr>
<tr><td>Core course</td><td colspan="2">ENGS 24 Science of Materials</td><td>1 course</td></tr>
<tr><td rowspan="2">Methods*
(Choose 1)</td><td colspan="2">PHYS 76 Methods of Experimental Physics</td><td rowspan="2">1 course</td></tr>
<tr><td colspan="2">ENGS 133 Methods of Materials Characterization</td></tr>
<tr><td rowspan="7">Electives*
(Choose 2 courses, each from a different group)</td><td rowspan="2">Group 1</td><td>ENGS 131 Science of Solid State Materials</td><td rowspan="7">2 courses</td></tr>
<tr><td>PHYS 73 Condensed Matter Physics I</td></tr>
<tr><td rowspan="2">Group 2</td><td>CHEM 108 Chemistry of Macromolecules: Physical Properties and Characterization</td></tr>
<tr><td>CHEM 109 Chemistry of Macromolecules: Synthesis and Characterization</td></tr>
<tr><td rowspan="3">Group 3</td><td>ENGS 73 Materials Processing and Selection</td></tr>
<tr><td>ENGS 132 Thermodynamics and Kinetics in Condensed Phases</td></tr>
<tr><td>PHYS 43 Statistical Physics</td></tr>
</table>

***** If ENGS 133 is taken as part of the requirement for the courses under Methods, you must choose at least one elective from outside the Engineering Sciences department.

OTHER MAJOR MODIFIED WITH ENGINEERING SCIENCES

Other Dartmouth majors may be modified with Engineering Sciences, with necessary approvals. A major modified with Engineering Sciences consists of 10 courses (6 from the major and 4 from Engineering Sciences), and should be planned as a unified, coherent whole, and not consist of a series of unrelated courses. Students should note that many Engineering Sciences courses require prerequisites in addition to those noted. No electives and ENGS courses numbered 20 or above may be taken under the Non-Recording Option.

For advice about the modified major, contact **Professor Douglas Van Citters**, Chair of the Department of Engineering Sciences and Associate Dean for Undergraduate Education, and the department chair of the other major.

PREREQUISITES		
Mathematics	MATH 3 Calculus	2 courses
	MATH 8 Calculus of Functions of One and Several Variables	
Physics (Choose 1 option)	PHYS 13 Introductory Physics I	1 or 2 courses
	PHYS 3 General Physics I and PHYS 4 General Physics II*	
REQUIRED COURSES		
Core course	ENGS 21 introduction to Engineering (Should be taken sophomore year.)	1 course
Electives (choose 3)	Any Engineering Sciences course numbered above 20 (excluding 80 and 87) coherent with the student's major field of study and approved, upon petition, by the Chair of the Department of Engineering Sciences.	3 courses

* Course must have been taken at Dartmouth. Advanced Placement (AP) credit not permitted.

OTHER MAJOR MODIFIED WITH HUMAN-CENTERED DESIGN

Other Dartmouth majors may be modified with Human-Centered Design, with necessary approvals. A major modified with Human-Centered Design requires three prerequisites, plus a total of four courses selected from course electives Ethnographic Methods and Human Factors/Psychology and Design. The modified major should be planned as a unified, coherent whole, and not consist of a series of unrelated courses.

Due to the potential overlap between the human-centered design courses and existing majors, there is potential for creating a program of study that does not add significant value beyond a straight major. Students pursuing the modification should note that 1) there should be a strong intellectual rationale, 2) the proposed plan should be adding something new and significant that is not possible with the straight major, and 3) there should not be significant overlap in courses between the modifier and the primary field of the major.

For advice about the modified major, contact **Professor Peter Robbie** (Engineering) or **Professor Lori Loeb** (Computer Science). Applications for this modified major should be addressed to **Professor Douglas Van Citters**.

PREREQUISITES			
Mathematics	MATH 3 Calculus		1 course
Engineering Sciences	ENGS 12 Design Thinking		2 courses
	ENGS 21 Introduction to Engineering		
REQUIRED COURSES			
Electives (Choose 4, with at least 1 course from each section) (continued)	Ethnographic Methods and Human Factors/ Psychology (Choose at least 1 course from this section)	ANTH 3 Intro to Cultural Anthropology	4 courses total (continued)
		ANTH 18 Intro to Research Methods in Cultural Anthropology	
		GEOG 11 Qualitative Methods and the Research Process in Geography	
		SOCY 11 Research Methods	
		PSYC 22 Learning	
		PSYC 23 Social Psychology	
		PSYC 28 Cognitive Psychology	
		PSYC 38 Cognitive Neuroscience	
		PSYC 43 Emotion	
		PSYC 50.02 Decision Making	
		PSYC 53.10 Social and Affective Motivations in Decision-Making	
		PSYC 53.12 The Behavior of Groups	
	Design Electives (Choose at least 1 course from this section) (continued)	ENGS 15.01 Senior Design Challenge	
		ENGS 15.02 Senior Design Challenge	
		ENGS 18 Systems Dynamics in Policy Design and Analysis	
		ENGS 44 Sustainable Design	
		ENGS 75 Product Design	
		COSC 23.01 Augmented and Virtual Reality Design	
		COSC 25.01 UI/UX Design I	
		COSC 25.02 UI/UX Design II	
		COSC 28 Advanced Projects in Digital Arts	
		COSC 29.04/PBS 15 Impact Design	
		FILM 51 Game Design	

Other Major modified by Human-Centered Design (continued on next page)

Other Major modified by Human-Centered Design (continued from previous page)

REQUIRED COURSES* (continued)			
(continued) **Electives** **(Choose 4, with at least 1 course from each section)**	(continued) Design Electives **(Choose at least 1 course from this section)**	PBPL 43/ECON 77 Social Entrepreneurship	(continued) 4 courses total
		SART 65 Architecture I	
		SART 66 Architecture II	
		SART 68 Architecture III	
		Independent study in a relevant discipline	

Bachelor of Engineering (BE)

engineering.dartmouth.edu/undergraduate/be

The Bachelor of Engineering (BE) program is a professional engineering degree accredited by the Engineering Accreditation Commission of ABET, enables students to specialize within specific engineering disciplines. The BE is equivalent to technical degrees such as the Bachelor of Science (BS) degrees at peer institutions.

Program Objectives

The BE degree program seeks to produce engineers who:

- 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.

Student Outcomes

BE graduates achieve these objectives through the ability to:

- Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics;
- Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors;
- Communicate effectively with a range of audiences;
- Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts;
- Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives;
- Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions;
- Acquire and apply new knowledge as needed, using appropriate learning strategies.

Enrollment and Degrees Awarded

ACADEMIC YEAR	STUDENTS ENROLLED	GRADUATION RATE
2020–2021	108	The graduate rate fluctuates between 96 and 97 percent.
2019–2020	120	
2018–2019	120	
2017–2018	91	

Courses Required

The BE requires a minimum of nine additional courses beyond the Bachelor of Arts (AB), with at least six courses with significant engineering design content. Additional required courses and electives include those in mathematics, basic science, and engineering sciences. Graduate-level courses taken as part of the BE program also count toward MS degree program requirements in order to earn an MS either simultaneously or one year after the BE.

Planning Ahead

Due to additional course requirements, the BE may require up to three terms of additional study depending on the courses taken during the student's first years at Dartmouth. Advanced standing upon entry to Dartmouth may shorten the time required.

AB+BE in Four Years

Students interested in earning the AB and BE concurrently within four years should meet with their faculty advisors as soon as possible to begin developing a multi-year course progression plan that will allow them to finish both degrees in less than five years, while meeting other personal academic goals. Prospective BE students should use the BE Program Plan spreadsheet, available on ThayerExpress (express.thayer.dartmouth.edu) to better understand degree requirements and to plan with their advisors their course of study.

AB+BE Programs for Computer Science and Physics Majors

The flexibility of the five-year BE program makes it possible for students majoring in Computer Science or Physics at Dartmouth to also obtain the BE with an additional year of study following the completion of the AB in their major. Computer Science and Physics majors could choose to minor in Engineering Sciences or choose to modify their majors with Engineering Sciences, then pursue requirements for the BE in their fifth year of study. Students should plan their programs in consultation with a professor in each department to ensure that all degree requirements are met.

BE+MS Degree Program

BE course credits also count toward Master of Science degree program credit requirements making it possible to earn an MS from Dartmouth one year after the BE, pending a willing faculty sponsor. Students may also earn the BE simultaneously with the MS. These students must have taken a substantial portion of the undergraduate program at Dartmouth or in one of its official exchange programs. Students should discuss their plans to satisfy both program requirements with the MS program director. At least one term prior to their thesis defense, the BE/MS candidate submits to the registrar a BE program plan approved by both their advisor and the BE program director.

BE+MEM Degree Program

With advanced planning, Dartmouth students may pursue the BE and MEM degrees simultaneously, reducing the time typically needed to complete both degrees by one term. Students are encouraged to apply to the MEM program during their senior year. Students should plan their programs with their advisor and with the MEM program director.

Dual-Degree Program

engineering.dartmouth.edu/undergraduate/dual

Students from partnering liberal arts colleges have the opportunity to study engineering at Dartmouth and earn the Bachelor of Engineering (BE) degree through the Dual-Degree program. Depending on the agreement between Dartmouth and their home institution, students spend either their junior or senior year as an exchange student at Dartmouth, earn their bachelor's degree from their home school, and then return to Dartmouth to complete a fifth year of engineering studies for the BE. Students enrolled in the Dual-Degree Program should consult with the dean or academic advisor at their home institution about the acceptability of Dartmouth courses toward degree requirements at their home school.

Preparation for the Dartmouth BE Program

Dual-Degree students should complete upper-level courses in math and science, either at their home institutions or at Dartmouth, that support their engineering interests. Examples include courses in linear algebra and differential equations; electromagnetism and atomic physics; organic and physical chemistry; or cell, molecular, or environmental biology. Requirements for BE also require a full year of humanities and social sciences (foreign language courses may be counted) that may require advanced planning.

Course Transfer from Home Institution

With approval of the Chair of the Department of Engineering Sciences, Dual-Degree students may transfer up to 11 STEM courses from their home institutions, in partial fulfillment of the degree requirements. Course credit transfers approved by the Dartmouth Registrar in partial satisfaction of AB degree requirements, with approval of the Chair, may be included in partial fulfillment of BE degree requirements. Courses transferred for course equivalency, or for engineering credit with no course equivalency, must be suitable for inclusion in a technical and applied science program and should be evaluated according to the process outlined by the Thayer Registrar for course transfers.

Courses transferred in fulfillment of the math and basic science requirements for the BE program will first be assessed by the Director of the Dual-Degree Program, the BE Program Committee, or appropriate math and science instructors at Dartmouth. Prior to approval for transfer, additional supporting material may be required, including course catalog descriptions, textbook information, syllabi, or other documentation.

Residency

Students who are registered and enrolled in two or more courses a term are considered full-time and as being "in residence." AB candidates should refer to Dartmouth's Organization, Regulations, and Courses for residency requirements. As many AB candidates are also BE candidates, the BE program does not have specific requirements for minimum residency, but students who wish to pursue the BE in their fifth year of study should plan for an additional one to three terms in residence.

Grade Standards for the BE

engineering.dartmouth.edu/courses/grading#grading-for-ab-and-be-candidates

Courses for the BE are assigned grades ranging from A (for distinctly superior work) to E (unacceptable for degree credit). The following guidelines offer general criteria for evaluation, with "plus" or "minus" 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.

GRADE	STANDARDS	GRADE POINT VALUES
A	Distinctly superior work	**A** = 4.0; **A-** = 3.67
B	Good work	**B+** = 3.33; **B** = 3.00; **B-** = 2.67
C	Acceptable mastery of course material	**C+** = 2.33; **C** = 2.00; **C-** = 1.67
D	Deficient in mastery of course material	**D** = 1.00
E	Serious deficiency in mastery of course material	**E** = 0.00

Minimum GPA Requirements

BE candidates must:

- Maintain a minimum grade point average of 2.00 in the courses required for the BE; and
- Maintain an overall minimum grade point average of 2.33 or better.

Students who fail to maintain a 2.33 average in any term will be placed on probation. BE candidates must also have no more than three courses with a grade below C, where C- is below C, and where this number of 3.00 is computed from all courses taken to satisfy BE requirements, excluding the prerequisites to the major in Engineering Sciences.

BACHELOR OF ENGINEERING (BE) REQUIREMENTS

The BE degree program requires a minimum of nine courses beyond the requirements for the AB degree. At least six courses must have significant engineering design content. Additional required courses and electives include those in mathematics, basic science, and engineering sciences. Only MATH 3, MATH 3, MATH 13, PHYS 13, and CHEM 5 may be taken under the Non-Recording Option for the BE. Detailed information for enrolled BE students about specific courses that satisfy accreditation and degree requirements can be found on the BE Program Plan spreadsheet, available on ThayerExpress (express.thayer.dartmouth.edu).

For additional advice, contact **Professor Douglas Van Citters**, Chair of the Department of Engineering Sciences and Associate Dean for Undergraduate Education.

BE REQUIRED COURSEWORK			
Mathematic and Basic Science	Math	MATH 3 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 and PHYS 14 Introductory Physics II	2 courses
	Chemistry	CHEM 5 General Chemistry	1 course
	Math and Science Electives (Choose 2)	Two non-introductory courses chosen from ASTR 15 and above; BIOL 12 and above (except 20 and 52); CHEM 6, 10 and above (except 63); EARS 31, 33, 35, 37, 40-52, 59, 62, 64, 66-76, 78, 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.	2 courses
Engineering Common Core Courses*	ENGS 20 Introduction to Scientific Computing or COSC 1 Introduction to Programming and Computation and COSC 10 Problem Solving via Object-Oriented Programming		4 or 5 courses
	ENGS 21 Introduction to Engineering (Should be taken sophomore year.)		
	ENGS 22 Systems		
	ENGS 23 Distributed Systems and Fields		
Engineering Distributive Core Courses (Choose 2)	ENGS 24 Science of Materials		2 courses
	ENGS 25 Introduction to Thermodynamics		
	ENGS 26 Control Theory		
	ENGS 27 Discrete and Probabilistic Systems		
	ENGS 28 Embedded Systems		
Engineering Gateway Courses** (Choose 2, each from a different discipline)	Electrical	ENGS 31 Digital Electronics	2 courses
		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	

BE Program Requirements (continued on next page)

BE Program Requirements (continued on next page)

BE DEGREE REQUIREMENTS (continued)	
Engineering and Computer Science Electives **(Choose 6)**	Three to four of the courses must form a coherent disciplinary concentration with one of these having significant design content.*** The remaining courses may be chosen from: • ENGS or ENGG courses numbered 24-88 (except 66, 75, 80 and 87); • ENGS or ENGG courses numbered 110-174, 192 and 199; • COSC 50-84 (except COSC 30, COSC 31, COSC 35, COSC 39, COSC 40, COSC 49, COSC 53, COSC 71, COSC 73 and COSC 74); and COSC 170-276 (except COSC 174, COSC 179, COSC 189, COSC 210). • Two of the three electives may be mathematics or basic science courses as listed above.
CULMINATING EXPERIENCE	
Engineering Design Capstone	ENGS 89 Engineering Design Methodology and Project Initiation and ENGS 90 Engineering Design Methodology and Project Completion • Taken as a two-course design sequence. • May count toward both AB and BE degrees. • 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.

* ENGS 20 counts as 0.5 course for BE credit.

** Students who modify the engineering sciences major with science, as well as dual-degree students with science majors, may take their gateway courses in the same discipline.

*** Understanding that the BE is a degree that prepares one for the engineering profession, students must choose at least three, but preferably four (or more) courses in which they increase their depth in an engineering field. At least one of these courses must have significant design content. This depth of studies must be intellectually coherent as defined together by the student and their faculty advisor. While some course plans might be self-evident as classically defined (e.g. "mechanical engineering" or "electrical engineering"), others might be more tailored to a student's chosen professional pathway. Students are therefore asked to provide a brief rationale for why they chose a certain group of courses. The courses need not build on one another but they must build on foundational courses in the engineering curriculum. These concentration courses allow the student to identify with a particular field of engineering on their resume, while still earning their degree in Engineering Sciences.

Course Transfer Credits for the BE

With approval of the Chair of the Department of Engineering Sciences, Dartmouth students admitted to the BE program may transfer up to four courses—two toward AB requirements and two toward BE requirements. Course credit transfers approved by the Dartmouth Registrar in partial satisfaction of AB requirements, with approval of the Associate Dean for Undergraduate Education, may be included in partial fulfillment of BE requirements.

Courses transferred for course equivalency, or for engineering credit with no course equivalency, must be suitable for inclusion in a technical and applied science program and should be evaluated according to the process outlined by the Thayer Registrar for course transfers.

Courses transferred in fulfillment of the math and natural science requirements for the BE will be assessed by the BE program committee, or appropriate math/science instructor at Dartmouth. Prior to approval for transfer, additional supporting material may be required, including course catalog descriptions, textbook information, syllabi, etc.

Undergraduate Admissions & Financial Aid

admissions.dartmouth.edu

AB Admissions and Financial Aid

Students interested in pursuing the Bachelor of Arts (AB) degree in any program must apply directly to Dartmouth's Office of Admissions and Financial Aid and be first admitted as a Dartmouth undergraduate. There is no separate admissions process to Thayer School of Engineering for the AB program.

Dartmouth's undergraduate admissions and financial office also administers the financial aid and scholarships for the AB degree program. Information about tuition, fees, and total estimated annual expenses for the current academic year is available online (admissions.dartmouth.edu/afford/cost-attendance).

BE Admissions and Financial Aid

engineering.dartmouth.edu/undergraduate/be#admissions

Dartmouth and Dual-Degree Students

Engineering Sciences majors and other approved modified majors, as well as Dual-Degree students enrolled in their first-year at Dartmouth, typically gain automatic admission to the BE program, pending submission of a formal application and an approved BE Program Plan.

Dartmouth and Dual-Degree students should **apply online** (engineering.dartmouth.edu/apply) **at least two terms prior** to the starting term of their BE program. At the time of application, students must also submit their completed BE Program Plan to the BE Program Committee for approval.

Other Applicants

Qualified candidates with a bachelor's degree substantially equivalent to the Dartmouth AB in Engineering Sciences, plus two upper-level electives in engineering, mathematics, or the natural sciences are eligible for admission to the BE program. Students who need no more than the equivalent of one term to satisfy prerequisites may be considered for admission as regular degree candidates. Students who are admitted with minor deficiencies may be admitted but will be required to complete additional undergraduate coursework.

Residents of the Upper Valley 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.

Non-Dartmouth applicants may request an application by emailing the Admissions Office at Thayer School of Engineering at Dartmouth (engineering.admissions@dartmouth.edu.) Prospective students from US and Canada may also call the office toll-free +1 (888) THAYER6 (1-888-842-9376). Students from outside the US and Canada may call +1 (603) 646-2606.

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

Office of Admissions
Thayer School of Engineering at Dartmouth
14 Engineering Drive
Hanover, NH 03755
engineering.admissions@dartmouth.edu

BE Tuition & Expenses

engineering.dartmouth.edu/undergraduate/be#tuition-expenses

Tuition covers the cost of instruction, student support services, the use and maintenance of our instructional facilities, and health care service through Dartmouth's Health Center. Information about tuition, fees, and total estimated annual expenses for the current academic year is available on Thayer and Dartmouth websites.

BE Financial Aid, Loans, and Scholarships

engineering.dartmouth.edu/undergraduate/be#financial-aid

Full-time BE students are eligible for financial aid in the form of partial-tuition scholarships, hourly employment as teaching assistants or other positions, fellowships, and loans. Information about scholarships, employment opportunities, fellowships, and loans, as well as how to apply for financial aid for the BE program is available on Thayer's website. Special and part-time students are *not* eligible for financial aid.

Policies & Regulations

Registration and Check-In

All students intending to be in residence must check in at the beginning of each term through an on-line check-in process. This practice lets the faculty and administration know who is in residence for the new term and facilitates identifying individual students who may require additional assistance. Students may begin check-in the day before classes begin and until the end of the third day of class, without a $50 penalty. After the third day until the 10th day of class, a $50 penalty will be assessed for late check-ins. Students, with good reason, may petition the Registrar for waiver of this charge. All financial accounts with Dartmouth 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

During the first five class days of a term, students may add, drop, or exchange courses online using DartHub, with no prior approval. When possible, students are strongly encouraged to arrange their course load during this period. During the second five class days of a term, a student may add or exchange courses by only with the approval of the instructor of the intended new course. After this period, and until 10 class days before the last class of the term, students may withdraw from a course at their own discretion.

Withdrawal from Courses

Students may withdraw from a course at their own discretion up until 10 class days before the last class of the term. The student must notify the instructor, as a courtesy, of their intention to withdraw and submit the withdrawal to the Registrar on or before the withdrawal deadline indicated for each term. The course remains on the student's transcript with the notation "W" for "Withdrew." During the last 10 days of classes in the term until the final examination begins, students must petition to withdraw from a course. Most petitions will not be approved, except in the most extreme medical or other circumstances. Once the final examination period has begun, it will be assumed that students intend to complete their courses and no course withdrawal requests will be accepted.

Withdrawal from 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 their candidacy must petition the dean or directors of their degree program in writing for readmission to the program.

Refund Policy

Refunds for students who withdraw after tuition has been paid, but **prior to registration and the first day of classes**, will be 100% of tuition. After the first day of classes, refunds will be calculated as follows:

- 90% of tuition for withdrawal during the **first week of the term**
- 75% of tuition for withdrawal during the **second and third weeks of the term**
- 50% of tuition for withdrawal during the **fourth week of the term**
- 25% of tuition for withdrawal during the **fifth week of the term**
- No tuition refunds will be issued after the fifth week of the term.

Other charges, such as payments to the Dartmouth Student Group Health Plan, are non-refundable. Other miscellaneous fees and charges, including student activity fees, are non-refundable if the student withdraws after registration and the first day of classes. All requests for refunds must be submitted in writing to:

Campus Billing
6132 McNutt Hall, Room 103
Hanover, NH 03755
Tel. +1 (603) 646-3230
Fax. +1 (603) 646-3455
campus.billing@dartmouth.edu

Any balance due the student, after adjustments are made, will be paid within 30 days. In any instance where it is felt that individual circumstances may warrant exception to the Refund Policy, the student may appeal in writing to the Controller

Graduate Studies

Graduate Studies

engineering.dartmouth.edu/graduate

Our masters and doctoral degree programs employ an integrated approach to scholarship, leadership, and technology transfer that empowers students to engage in pioneering work to advance critical knowledge and drive solutions to the world's most critical challenges. All graduate programs are highly collaborative, with opportunities to engage with faculty and students across Dartmouth, the Dartmouth-Hitchcock Medical Center, Norris Cotton Cancer Center, and other affiliated programs.

Master's Degree Programs

Master of Science (MS)

engineering.dartmouth.edu/graduate/ms

The Master of Science (MS) program stresses innovative research, advanced levels of engineering skills, and project management experience. MS candidates take coursework in mathematics and engineering and acquire depth of knowledge in a particular engineering field through research and the completion of a thesis.

Master of Engineering (MEng)

engineering.dartmouth.edu/graduate/meng

The Master of Engineering (MEng) degree is an entirely course-based program that prepares students for a professional engineering career through a foundational mastery in one of six engineering tracks. The MEng does not require a thesis.

Master of Engineering Management (MEM)

mem.dartmouth.edu

The Master of Engineering Management (MEM) is a professional degree for students interested in becoming leaders in both the engineering and business aspects of technology. MEM courses are taught by faculty from Thayer and the Tuck School of Business at Dartmouth, and students are required to complete an industry internship.

Doctoral Degree Programs

Doctor of Philosophy (PhD)

engineering.dartmouth.edu/graduate/phd

The Doctor of Philosophy (PhD) degree in Engineering Sciences is aimed at students seeking to engage in multi-year, high impact research within a focused discipline or field. PhD students typically are funded through sponsored research or a fellowship and acquire not only technical depth, but also a breadth of knowledge and skills through multidisciplinary collaborations across Dartmouth.

PhD Innovation Program

engineering.dartmouth.edu/graduate/phdi

The PhD Innovation Program is a highly selective fellowship for PhD students interested in entrepreneurship and translational research. PhD Innovation Fellows augment their doctoral studies with additional coursework and receive funding and other support to launch their own start-ups and take their research discoveries to market.

PhD Innovation Program: Surgical Track

engineering.dartmouth.edu/graduate/phdi/tpsi

PhD Innovation Fellows interested in the research and development of innovations that improve surgery and surgical outcomes may pursue the "surgical track" through the Training Program in Surgical Innovation (TPSI). The program prepares graduates for careers in surgical research and development of technology that can help solve problems, save lives, and improve outcomes in operating rooms.

PhD + Doctor of Medicine (MD-PhD)

engineering.dartmouth.edu/graduate/phd-md

The combined Doctor of Medicine and Doctor of Philosophy (MD-PhD) degree is for students seeking to conduct in-depth research and receive extensive training in both medicine and biomedical engineering. Students must apply and be admitted to both Thayer and Geisel School of Medicine at Dartmouth and complete requirements for both the MD and PhD.

Minimum Residency Requirements

Each graduate degree program has its own minimum residency requirements. Students who are registered and enrolled in two or more courses a term are considered full-time and as being "in residence." Please check each graduate degree program for specific requirements.

Academic Honor Principles and Code of Conduct

All graduate students, upon matriculation, sign an agreement to abide by the academic honor principles and code of conduct established by Dartmouth College found in the Graduate Student Handbook on ThayerExpress (express.thayer.dartmouth.edu).

Service to Society

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

Grade Standards for the MEM, MEng, MS, and PhD

engineering.dartmouth.edu/courses/grading#grading-for-mem-ms-and-ph-d-candidates

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

GRADE	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

Minimum Grade Requirements

MEM candidates must enroll in no fewer than 14 courses total, and earn no fewer than 12 P (Pass) or HP (High Pass) grades.

MEng, MS, and PhD candidates must earn no more than one LP (Low Pass) grade for every six courses.

Any student earning one LP (Low Pass) or NC (No Credit) grade will receive a letter of warning from the MEM program director. Additional details about the Student Probation Policy can be found in the Thayer Graduate Student Handbook.

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.

Program Overview

The MEM curriculum integrates engineering, mathematics, and core management courses, with elective courses drawing from engineering and management, or 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

MEM candidates are required to hold a bachelor's level degree from an accredited undergraduate institution. While students may hold undergraduate degrees in a variety of academic fields, MEM students generally hold degrees in engineering or one of the physical sciences or have previous experience in these areas.

Residency and Program Duration

Students are required to be enrolled full-time and in residence for a minimum of three academic terms. The MEM degree is typically completed in **four academic terms plus one summer internship**. A student who enters in the fall term in September usually completes the program 15 months later near the end of the following November.

Course Requirements

The number of required courses will depend on the student's preparation prior to entering the program. Students from a college or university other than Dartmouth generally take 14 courses, including the ENGG 390, the industry internship course. Dartmouth students, including Dual-Degree students, may count ENGS 93 Statistical Methods in Engineering toward the MEM degree, even if it was taken as part of the AB and/or BE requirements. With the exception of the first fall term, when MEM students typically take ENGM 387 in addition to the three core engineering management courses, a four-course load with courses used to satisfy MEM requirements must be pre-approved by the MEM Director.

Industry Internship

In addition to coursework, MEM students participate in an industry internship to satisfy the ENGG 390 Master of Engineering Management Project requirement, usually during the summer term following their first year. The internship may focus on engineering or management or both, and the project should define a practical need, conceive and evaluate potential solutions, describe appropriate analytical, experimental, and economic evaluations, and provide recommendations for further action. Students must enroll for ENGG 390 during the same term as their internship, and may not enroll in more than one other course while taking ENGG 390.

MASTER OF ENGINEERING MANAGEMENT (MEM) REQUIREMENTS

REQUIRED COURSEWORK		
Engineering Management Core Courses	ENGS 93 Statistical Methods in Engineering*	8 courses
	ENGM 178 Technology Assessment	
	ENGM 179.1 Strategy (0.5 credit) ENGM 179.2 Organizational Behavior (0.5 credit)	
	ENGM 180 Accounting and Finance	
	ENGM 181 Marketing	
	ENGM 183 Operations Management	
	ENGM 387 MEM Professional Skills	
	ENGG 390 Master of Engineering Management Project	
Applied Mathematics** **(Choose 2)**	ENGS 103 Operations Research	2 courses
	ENGS 108 Applied Machine Learning	
	ENGM 182 Data Analytics	
	ENGM 184 Introduction to Optimization Methods	
Open Electives*** **(Choose 4)**	Any graduate-level Engineering Sciences courses.	4 courses
	Business and management courses from Tuck School of Business at Dartmouth****	
	Graduate-level courses from Dartmouth science departments	
	Courses from Geisel School of Medicine at Dartmouth	
	Courses in Environmental Law from Vermont Law School	
	Courses from The Dartmouth Institute for Health Policy & Clinical Practice (TDI)	
TOTAL		14 courses

* Dartmouth students, including Dual-Degree students, may count ENGS 93 toward the MEM degree, even if taken as part of the AB and/or BE requirements.
** Other applied mathematics courses may be substituted with MEM Director approval.
*** All elective courses require permission from the instructor and prior approval of the MEM Director.
**** MEM tuition covers 2 courses from Tuck School; extra tuition will be charged for additional courses.

POPULAR ENGINEERING ELECTIVE COURSES

- ENGS 103 Operations Research
- ENGS 108 Applied Machine Learning
- ENGS 171 Industrial Ecology
- ENGS 173 Energy Utilization
- ENGM 182 Data Analytics
- 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
- ENGM 191 Product Design and Development

POPULAR BUSINESS ELECTIVE COURSES

- Data Mining for Business Analytics
- Global Strategy & Implementation
- Financial Reporting & Statement Analysis
- Pricing Strategies & Tactics
- Selling and Sales Leadership
- Power and Influence
- The CEO Experience
- Leadership Out of the Box
- Countries & Companies in the International Economy
- Energy Economics

MEM Program Options

mem.dartmouth.edu/options

STANDARD MEM COURSE SEQUENCE

The stand-alone MEM degree requires 14 courses and is typically completed in 15 months, starting in the fall term (September) and completing the following November.

STANDARD MEM COURSE SEQUENCE	
Fall Term	ENGS 93 Statistical Methods in Engineering
	ENGM 181 Marketing
	ENGM 178 Technology Assessment
	ENGM 387 MEM Professional Skills
Winter Term	ENGM 183 Operations Management
	Elective
	Elective
Spring Term	ENGM 180 Accounting and Finance
	Elective
	Elective
Summer Term	ENGG 390 Master of Engineering Management Project/Internship
Fall Term	ENGM 179.1 Strategy (0.5 credit) ENGM 179.2 Organizational Behavior (0.5 credit)
	Elective
	Elective

BE+MEM JOINT DEGREE SEQUENCE (for Dartmouth Students)

With advanced planning, students enrolled in Dartmouth's BE program are able to pursue both BE and MEM degrees simultaneously, reducing the time typically needed to complete both degrees by one term. Students are encouraged to apply to the MEM program during their senior year.

BE+MEM COURSE SEQUENCE		
BE Year	Fall Term	ENGS 89 Engineering Design Methodology and Project Initiation (BE)
		BE Elective
		ENGM 178 Technology Assessment (MEM)
		ENGM 387 MEM Professional Skills (MEM)
	Winter Term	ENGS 90 Engineering Design Methodology and Project Completion (BE)
		ENGS 93 Statistical Methods in Engineering (BE & MEM)
		BE Elective
	Spring Term	*BE Elective*
		BE Elective
		MEM Elective
Summer Term, between BE and MEM years		ENGG 390 Master of Engineering Management Project/Internship (MEM)

BE+MEM Course Sequence (continued on next page)

BE+MEM Course Sequence (continued from previous page)

BE+MEM COURSE SEQUENCE (continued)		
MEM Year	Fall Term	ENGM 181 Marketing
		ENGM 179.1 Strategy (0.5 credit) ENGM 179.2 Organizational Behavior (0.5 credit)
		MEM Elective
	Winter Term	ENGM 183 Operations Management
		MEM Elective
		MEM Elective
	Spring Term	ENGM 180 Accounting and Finance
		MEM Elective
		MEM Elective

MEM+MBA Joint Degree

Students interested in tailoring their experience to gain both the management skills taught at the Tuck School of Business and the technical skills taught at the Thayer School of Engineering will benefit from the joint MEM+MBA degree. This program is intended to develop leaders for careers that combine engineering/technology and business management.

Students must apply for and be admitted to both Tuck and Thayer, and it is recommended that students begin their studies in the MBA program. Tuck students typically apply for admission to Thayer during their first year.

Students who pursue the joint degree can complete the program in as little as 2.5 years (a total of eight terms, including the summer). All degree requirements are the same, but the business core and MEM professional skills course (ENGM 179, 180, 181, 183, 387) are waived for students that complete their MBA degree at Tuck.

Duke University Exchange

Dartmouth MEM students may choose to spend their second fall term at Duke taking equivalent courses in Duke's MEM program.

MEM Program Directors

Geoffrey G. Parker
Professor of Engineering
Director, MEM Program

Jessica Duda
Interim Associate Director, MEM Program

Thayer School of Engineering Faculty

Eric Bish
Visiting Assistant Professor of Engineering

George Cybenko
Dorothy and Walter Gramm Professor of Engineering

Amro M. Farid
Associate Professor of Engineering

Eric R. Fossum
John H. Krehbiel Sr. Professor for Emerging Technologies
Director of the PhD Innovation Program
Vice Provost for Office of Entrepreneurship and Technology Transfer

Oliver Goodenough
Adjunct Professor of Engineering
Professor, Vermont Law School

Ryan J. Halter
Associate Professor of Engineering

Mark Laser
Associate Professor of Engineering

Ronald C. Lasky
Professor of Engineering

Wesley J. Marrero
Assistant Professor of Engineering

Erin Mayfield
Hodgson Family Assistant Professor of Engineering

Elizabeth L. Murnane
Charles H. Gaut and Charles A. Norberg Assistant Professor of Engineering

Keith Paulsen
Robert A. Pritzker Chair in Biomedical Engineering

Vikrant Vaze
Assistant Professor of Engineering

Tuck School of Business Faculty

Laurens Debo
Associate Professor of Business Administration

Ryan Hamilton
Visiting Associate Professor of Marketing

Adam M. Kleinbaum
Associate Professor of Business Administration

Catherine A. Maritan
Visiting Professor of Business Administration

Richard C. Sansing
Noble Foundation Professor of Accounting

Felipe Severino
Assistant Professor of Business Administration

Sharmistha Sikdar
Assistant Professor of Business Administration

Master of Engineering (MEng)

engineering.dartmouth.edu/graduate/meng

The Master of Engineering (MEng) degree program is aimed at students seeking to become professional engineers or engineers already in the profession seeking to add depth or acquire specialized knowledge within an area of study.

Program Overview

The MEng is a course-based degree program that does not require the completion of a thesis. The program can be tailored to individual interests with six specialized tracks in:

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

Through the program, graduates acquire a depth of knowledge through courses specific to their specialized engineering track, as well as basic competency in applied mathematics and engineering and a breadth of understanding of various engineering disciplines through electives.

Prerequisites

MEng candidates are required to hold a bachelor's level degree in engineering or a bachelor's level degree in a scientific field such as Physics, Chemistry, and computer sciences from an accredited institution. Admitted students with degrees from non-accredited institutions may be required to take the necessary prerequisite courses, in addition to courses for the MEng, to fulfill the requirements of the degree.

Advisors

Faculty advisors aid MEng students in developing their course of study, which is submitted to and approved by Thayer's Graduate Programs Committee during the student's first term of residency.

Degree Requirements

Coursework

Students enrolled in the MEng program are expected to follow one pre-defined specialization engineering track. The program requires a total of nine courses. Unless otherwise specified, five of those courses are chosen from a list of core courses, and the remaining four electives can consist of any graduate-level engineering or science courses offered at Dartmouth. Additional courses may be required for students with no previous engineering background.

With the exception of ENGM 191: Product Design and Development, which must be elected as part of the MEng Design Project, MEng students may not take ENGM courses for credit.

Engineering Design Elective

MEng students who want to combine engineering design with elements of human-centered design may choose a design project elective, a 3-course sequence that can also be used to partially fulfill the 4-course elective requirements. The design project courses provide MEng students with both coursework opportunities for real-world experience.

The three courses may be counted towards the four elective course requirements. Students who choose the design elective will work directly with an industry sponsor to address a particular design challenge to gain unique leadership skills and hands-on technical experience. Projects are sourced through the Cook Engineering Design

Center (CEDC). Interested students who are accepted into the MEng program are interviewed before enrollment about their professional interests to facilitate the matching of students with potential projects.

Residency and Program Duration

The residency requirement of the MEng is flexible, and students may follow an "in residence" schedule that fits their professional schedules. Students enrolled full-time complete the program in three terms (nine months), taking three courses at a time. Part-time students may take one or more courses at a time over five or more terms. Students must complete the MEng program within six years of initial enrollment.

Transition to or from MS or PhD Programs

Highly qualified students may be allowed to transition to either the MS or PhD degree programs with the approval of the MS-PhD Committee and at the invitation of a willing faculty sponsor. Students enrolled in either the MS or PhD programs may only transition into the MEng upon request from their faculty advisor.

MEng: BIOLOGICAL/CHEMICAL ENGINEERING TRACK

Biological/chemical engineering exists at the interface of engineering, biological, and chemical sciences. This interdisciplinary track is for engineers who want to add depth to or acquire new specialized knowledge in bioengineering to model, design, build, and optimize biological and chemical systems to help tackle unmet needs in medicine, agriculture, the environment, and more.

<table>
<tr><th colspan="4">REQUIRED COURSEWORK</th></tr>
<tr><td rowspan="17">Core Courses
(Choose 5)</td><td colspan="2">ENGS 108 Applied Machine Learning**</td><td rowspan="17">5 courses</td></tr>
<tr><td colspan="2">ENGS 150 Intermediate Fluid Mechanics</td></tr>
<tr><td colspan="2">ENGS 155 Intermediate Thermodynamics</td></tr>
<tr><td colspan="2">ENGS 156 Heat, Mass, and Momentum Transfer</td></tr>
<tr><td colspan="2">ENGS 157 Chemical Process Design</td></tr>
<tr><td colspan="2">ENGS 158 Chemical Kinetics and Reactors</td></tr>
<tr><td colspan="2">ENGS 159 Molecular Sensors & Nanodevices in Biomedical Engineering</td></tr>
<tr><td colspan="2">ENGS 160 Biotechnology and Biochemical Engineering</td></tr>
<tr><td colspan="2">ENGS 161 Metabolic Engineering</td></tr>
<tr><td colspan="2">ENGS 162 Basic Biological Circuit Engineering</td></tr>
<tr><td colspan="2">ENGS 163 Advanced Protein Engineering</td></tr>
<tr><td colspan="2">ENGS 165 Biomaterials</td></tr>
<tr><td colspan="2">ENGG 260 Advances in Biotechnology</td></tr>
<tr><td colspan="2">ENGG 261 Biomass Energy Systems</td></tr>
<tr><td colspan="2">ENGS 262 Advanced Biological Circuit Engineering</td></tr>
<tr><td colspan="2">BIOC 101 Molecular Information in Biological Systems</td></tr>
<tr><td colspan="2">COSC 175 Introduction to Bioinformatics (Applied Math)***</td></tr>
<tr><td rowspan="3">Electives*
(Choose 4)</td><td>Engineering</td><td>Any graduate-level Engineering Sciences courses</td><td rowspan="3">4 courses</td></tr>
<tr><td>Design Project</td><td>Students enrolled in the design project elective may take the following 3-course sequence to partially fulfill the 4-course elective requirement.
• ENGM 191 Product Design and Development
• ENGG 199.10 MEng Design Project Initiation
• ENGG 199.11 MEng Design Project Completion</td></tr>
<tr><td>Sciences</td><td>Any graduate-level Science courses, including:
• COSC 174 Machine Learning and Statistical Data Analysis**
• COSC 186 Computational Structural Biology
• COSC 189 Topics in Computational Immunology
• CHEM 101.2 Statistical Thermodynamics
• CHEM 161.2 Biomolecular Simulations
• CHEM 161.4 Structure and Dynamics of Biomolecules
• MICR 142: Advanced Cellular and Molecular Immunology
• MICR 144: Cellular and Molecular Basis of Immunity
• MICR 149: Microbial Physiology and Metabolism
• QBS 108 Applied Machine Learning**
• QBS 120 Foundations of Biostatistics I: Statistical Theory for the Quantitative Biomedical Sciences
• QBS 121 Foundations of Biostatistics II: Regression
• QBS 149 Mathematics and Probability for Statistics and Data Mining
• QBS 175 Foundations of Bioinformatics II***</td></tr>
</table>

* Students may choose electives from any graduate-level engineering and sciences courses offered at Dartmouth. The courses listed here are for recommended students who seek additional further depth of study in their chosen track.
** ENGS 108, COSC 174, and QBS 108 are equivalent, and only one may be taken for credit.
*** COSC 175 and QBS 175 are equivalent courses. Only one may be taken for credit.

MEng: BIOMEDICAL ENGINEERING TRACK

Biomedical engineering is the broad area of study in which engineers use an interdisciplinary approach to solve problems in the medical field, often associated with the interaction between living and non-living systems. This track is for engineers who want to add depth to or acquire new specialized knowledge in biomedical engineering to design, build, test, and/or analyze biological systems, diagnostics, devices, and treatment modalities.

<table>
<tr><th colspan="4">REQUIRED COURSEWORK</th></tr>
<tr><td rowspan="13">Core Courses
(Choose 5)</td><td colspan="2">ENGS 111 Digital Image Processing</td><td rowspan="13">5 courses</td></tr>
<tr><td colspan="2">ENGG 113 Image Visualization and Analysis</td></tr>
<tr><td colspan="2">ENGS 129 Biomedical Circuits and Systems</td></tr>
<tr><td colspan="2">ENGS 156 Heat, Mass and Momentum Transfer</td></tr>
<tr><td colspan="2">ENGS 159 Molecular Sensors & Nanodevices in Biomedical Engineering</td></tr>
<tr><td colspan="2">ENGS 162 Basic Biological Circuit Engineering</td></tr>
<tr><td colspan="2">ENGS 165 Biomaterials</td></tr>
<tr><td colspan="2">ENGG 166 Quantitative Human Physiology</td></tr>
<tr><td colspan="2">ENGG 168 Biomedical Radiation Transport</td></tr>
<tr><td colspan="2">ENGS 169 Intermediate Biomedical Engineering</td></tr>
<tr><td colspan="2">ENGS 199 Advanced Imaging (if offered)</td></tr>
<tr><td colspan="2">ENGS 262 Advanced Biological Circuit Engineering</td></tr>
<tr><td colspan="2">ENGG 325 Introduction to Surgical Innovation</td></tr>
<tr><td rowspan="3">Electives*
(Choose 4)</td><td>Engineering</td><td>Any graduate-level Engineering Sciences courses, including:
• ENGS 91 Numerical Methods in Computation
• ENGS 92 Fourier Transforms and Complex Variables
• ENGS 93 Statistical Methods in Engineering
• ENGS 105 Computational Methods for Partial Differential Equations I
• ENGS 108 Applied Machine Learning
• ENGS 110 Signal Processing</td><td rowspan="3">4 courses</td></tr>
<tr><td>Design Project</td><td>Students enrolled in the design project elective may take the following 3-course sequence to partially fulfill the 4-course elective requirement.
• ENGM 191 Product Design and Development
• ENGG 199.10 MEng Design Project Initiation
• ENGG 199.11 MEng Design Project Completion</td></tr>
<tr><td>Sciences</td><td>Any graduate-level Science courses</td></tr>
</table>

* Students may choose electives from any graduate-level engineering and sciences offered at Dartmouth. The recommended courses listed here are for students who seek additional courses that allow for further depth of study in their chosen track.

MEng: ELECTRICAL/COMPUTER ENGINEERING TRACK

Electrical and computer engineering leverages the fundamental principles of electricity to advance today's emerging technologies, such as advanced communication networks, self-powered sensors, wearable devices, cognitive medical imaging, and autonomous vehicles. In this track, students may focus on a single specialization within electrical and computer engineering, or build an individualized curriculum from a combination of complementary subfields within the track.

REQUIRED COURSEWORK			
Core Courses **(Choose 4 courses, all from one subfield.)**	Computer Engineering	ENGS 93 Statistical Methods in Engineering	4 courses
		ENGS 108 Applied Machine Learning *or* COSC 174 Machine Learning and Statistical Data Analysis	
		ENGS 112 Modern Information Technologies	
		ENGS 128 Advanced Digital System Design	
		COSC 55 Security and Privacy	
		COSC 178 Deep Learning	
	Control, Signal Processing, and Image Processing	ENGS 92 Fourier Transforms and Complex Variables	
		ENGS 110 Signal Processing	
		ENGS 111 Digital Image Processing	
		ENGG 113 Image Visualization and Analysis	
		ENGS 145 Modern Control Theory	
		ENGS 147 Mechatronics	
		ENGG 149 Introduction to Systems Identification	
		ENGS 167 Medical Imaging	
	Devices and Circuits	ENGG 122 Advanced Topics in Semiconductor Devices	
		ENGS 125 Power Electronics and Electromechanical Energy Conversion	
		ENGS 126 Analog Integrated Circuits	
		ENGS 129 Biomedical Circuits and Systems	
		ENGS 131 Science of Solid State Materials	
		ENGS 159 Molecular Sensors & Nanodevices in Biomedical Engineering	
		ENGS 162 Basic Biological Circuit Engineering	
		ENGS 262 Advanced Biological Circuit Engineering	
	Optics and Electromagnetics	ENGS 120 Electromagnetic Waves: Analytical and Modeling Approaches	
		ENGS 123: Optics	
		ENGS 220 Electromagnetic Wave Theory	
		ENGS 105: Computational Methods for Partial Differential Equations I	
		PHYS 105: Electromagnetic Theory I Winter	
		PHYS 106: Electromagnetic Theory II Spring	
	Miniaturized and Mobile Health Sensors	ENGS 129: Biomedical Circuits and Systems	
		ENGS 159: Molecular Sensors & Nanodevices in Biomedical Engineering	
		ENGS 125: Power Electronics and Electromechanical Energy Conversion	
		ENGS 169: Intermediate Biomedical Engineering	
		ENGS 108: Applied Machine Learning	

MEng: Electrical/Computer Engineering Track Requirements (continued on next page)

MEng: Electrical/Computer Engineering Track Requirements (continued from previous page)

REQUIRED COURSEWORK (continued)			
Electives* (Choose 5)	Engineering	Any graduate-level Engineering Sciences courses	5 courses
	Design Project	Students enrolled in the design project elective may take the following 3-course sequence to partially fulfill the 4-course elective requirement. • ENGM 191 Product Design and Development • ENGG 199.10 MEng Design Project Initiation • ENGG 199.11 MEng Design Project Completion	
	Sciences	Any graduate-level Science courses	

* Students may choose electives from any graduate-level engineering and sciences offered at Dartmouth, but at least five of the nine total must be from Engineering (ie. ENGS or ENGG courses).

MEng: ENERGY ENGINEERING TRACK

Energy engineering aims to increase the efficiency of energy conversion, storage, transmission and utilization, to accelerate the transition to sustainable energy sources, and to improve access to and management of energy systems. This track is for engineers who want to add depth to or acquire new specialized knowledge in energy engineering in energy technologies, systems, challenges, and opportunities.

REQUIRED COURSEWORK			
Core Courses (Choose 5)	ENGS 171: Industrial Ecology		5 courses
	ENGS 172: Climate Change and Engineering		
	ENGG 173: Energy Utilization		
	ENGS 174: Energy Conversion		
	ENGS 175: Energy Systems		
Electives* (Choose 4)	Engineering	Any graduate-level Engineering Sciences courses, including: • ENGS 91 Numerical Methods in Computation • ENGG 103 Operations Research • ENGS 104 Optimization Methods for Engineering Applications • ENGS 106 Numerical Linear Algebral • ENGS 108 Applied Machine Learning • ENGS 110 Signal Processing • ENGS 114 Networked Multi-Agent Systems • ENGS 115 Parallel Computing • ENGS 145 Modern Control Theory • ENGG 177 Decision-Making under Risk and Uncertainty • ENGM 182 Data Analytics • ENGG 199 Model-Based Systems Engineering, Analysis, and Simulation • ENGS 202 Nonlinear Systems	4 courses
	Design Project	Students enrolled in the design project elective may take the following 3-course sequence to partially fulfill the 4-course elective requirement. • ENGM 191 Product Design and Development • ENGG 199.10 MEng Design Project Initiation • ENGG 199.11 MEng Design Project Completion	
	Sciences	Any graduate-level Science courses, including: • COSC 170 Numerical and Computational Tools for Applied Science • COSC 174 Machine Learning and Statistical Data Analysis • COSC 184 Mathematical Optimization and Modeling • COSC 271 Numerical Linear Algebra	

* Students may choose electives from any graduate-level engineering and sciences offered at Dartmouth. The recommended courses listed here are for students who seek additional courses that allow for further depth of study in their chosen track.

MEng: MATERIALS SCIENCES AND ENGINEERING TRACK

Materials scientists and engineers work with diverse types of materials (e.g., metals, polymers, ceramics, liquid crystals, composites) to better understand and create advanced materials with unprecedented functional properties with applications in medicine, energy, healthcare, and other applications.. This track is for engineers who want to add depth to or acquire new specialized knowledge in materials science and engineering.

<table>
<tr><th colspan="4">REQUIRED COURSEWORK</th></tr>
<tr><td rowspan="12">Core Courses
(Choose 5)</td><td colspan="2">ENGS 130 Mechanical Behavior of Materials</td><td rowspan="12">5 courses</td></tr>
<tr><td colspan="2">ENGS 131 Science of Solid State Materials</td></tr>
<tr><td colspan="2">ENGS 132 Thermodynamics and Kinetics in Condensed Phases</td></tr>
<tr><td colspan="2">ENGS 133 Methods of Materials Characterization</td></tr>
<tr><td colspan="2">ENGS 134 Nanotechnology</td></tr>
<tr><td colspan="2">ENGS 135 Thin Films and Microfabrication Technology</td></tr>
<tr><td colspan="2">ENGG 138 Corrosion and Degradation of Materials</td></tr>
<tr><td colspan="2">ENGS 165 Biomaterials</td></tr>
<tr><td colspan="2">ENGG 230 Fatigue and Fracture</td></tr>
<tr><td colspan="2">ENGG 332 Topics in Plastic Flow and Fracture of Solids</td></tr>
<tr><td colspan="2">ENGG 339 Advanced Electron Microscopy</td></tr>
<tr><td colspan="2">ENGG 365 Advanced Biomaterials</td></tr>
<tr><td rowspan="3">Electives*
(Choose 4)</td><td>Engineering</td><td>Any graduate-level Engineering Sciences courses, including:
• ENGS 91 Numerical Methods in Computation
• ENGS 93 Statistical Methods in Engineering
• ENGS 105 Computational Methods for Partial Differential Equations I
• ENGS 108 Applied Machine Learning
• ENGS 124 Optical Devices and Systems</td><td rowspan="3">4 courses</td></tr>
<tr><td>Design Project</td><td>Students enrolled in the design project elective may take the following 3-course sequence to partially fulfill the 4-course elective requirement.
• ENGM 191 Product Design and Development
• ENGG 199.10 MEng Design Project Initiation
• ENGG 199.11 MEng Design Project Completion</td></tr>
<tr><td>Sciences</td><td>Any graduate-level Science courses, including:
• CHEM 101.2: Statistical Thermodynamics
• CHEM 101.4: Chemistry of Macromolecules</td></tr>
</table>

* Students may choose electives from any graduate-level engineering and sciences offered at Dartmouth. The recommended courses listed here are for students who seek additional courses that allow for further depth of study in their chosen track.

MEng: MECHANICAL ENGINEERING TRACK

REQUIRED COURSEWORK			
Core Courses (Choose 5)	ENGS 130 Mechanical Behavior of Materials		5 courses
	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 155 Intermediate Thermodynamics		
	ENGS 156 Heat, Mass and Momentum Transfer		
	ENGG 240 Kinematics and Dynamics of Machinery		
Electives* (Choose 4)	Engineering	Any graduate-level Engineering Sciences courses, including: • ENGS 91 Numerical Methods in Computation • ENGS 93 Statistical Methods in Engineering • ENGS 105 Computational Methods for Partial Differential Equations I • ENGS 108 Applied Machine Learning • ENGG 173 Energy Utilization	4 courses
	Design Project	Students enrolled in the design project elective may take the following 3-course sequence to partially fulfill the 4-course elective requirement. • ENGM 191 Product Design and Development • ENGG 199.10 MEng Design Project Initiation • ENGG 199.11 MEng Design Project Completion	
	Sciences	Any graduate-level Science courses.	

* Students may choose electives from any graduate-level engineering and sciences offered at Dartmouth. The recommended courses listed here are for students who seek additional courses that allow for further depth of study in their chosen track.

Master of Science (MS)

engineering.dartmouth.edu/graduate/ms

The Master of Science in Engineering Sciences degree program focuses on innovative engineering research, advancing students' levels of engineering skills, and providing extensive project management experience.

Program Overview

The candidates for the MS in Engineering Sciences degree acquire basic competency in applied mathematics and engineering, a breadth of knowledge through a range of coursework, and a depth of knowledge through both focused coursework and research. MS candidates are required to complete a thesis for graduation, and students are encouraged to arrange their thesis research topic in advance with a faculty willing to sponsor the students in the program.

Matching Interests to Faculty

MS students are funded through a professor’s sponsored research or a fellowship throughout the thesis phase of their studies at Thayer. Therefore, applicants interested in pursuing particular areas of research should contact Thayer faculty within their area of interest for an initial conversation about the availability of funded research opportunities.

Prerequisites

MS candidates are required to hold a bachelor’s level degree in engineering or a bachelor’s level degree, generally in engineering or in one of the physical sciences, from an accredited institution.

Advisors

Faculty advisors aid MS students in developing their course of study, which is submitted to and approved by Thayer’s Graduate Programs Committee during the student’s first term of residency.

Degree Requirements

Coursework

All students entering the program are required to take six graduate-level courses, beyond the AB degree, which may simultaneously be counted for the Bachelor of Engineering (BE) degree. 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. More information is available on the following pages.

Research & Thesis

In addition, students are also required to complete research that leads to a written thesis that demonstrates a depth of knowledge in a specific field of engineering research or design. Candidates must also present a public oral defense of the thesis, which is conducted by the candidate's thesis committee. More information is available on the following pages.

Residency Requirements

MS students are required to be in residence for a minimum of three terms. Students who are registered and enrolled in two or more courses a term are considered full-time and as being “in residence.”

MS: COURSEWORK, RESEARCH, & THESIS REQUIREMENTS

REQUIRED COURSEWORK		
Applied Mathematics **(Choose 1 or more)**	ENGS 91 Numerical Methods in Computation	1 or more courses
	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	
Engineering Depth **(Choose 3 or more)**	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. Engineering Management courses are not permitted.	3 or more courses
Engineering Breadth **(Choose 2 or more)**	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
REQUIRED RESEARCH & THESIS		
Research Course	ENGG 700 Responsible and Ethical Conduct of Research	
Research and Written Thesis	Research that demonstrates a depth of knowledge in a specific field of engineering research or design that leads to a written thesis.	
Oral Defense	An oral defense of the thesis	

MS Research and Written Thesis

The MS research that leads to the written thesis must demonstrate a depth of knowledge in a specific field of engineering research or design.

Thesis Committee

The MS thesis committee typically consists of three Dartmouth faculty members (including the student's thesis advisor); one of the three may be from outside the program of study.

Oral Defense

The candidate is required to present 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. Candidates 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 an electronic copy (eg. PDF) of the thesis must be submitted to the Registrar for archiving. Copyright to the thesis is held by the Trustees of Dartmouth College. Additional information is available online on the MS degree page or from the Thayer Registrar.

Dual Degrees

BE+MS

Dartmouth's Bachelor of Engineering (BE) degree program course credits taken at the graduate level also count toward MS degree program credit requirements making it possible to earn an MS one year after the BE. 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.

Doctor of Medicine (MD) + Master of Science (MS)

engineering.dartmouth.edu/graduate/ms/ms-md

The Doctor of Medicine (MD) + Master of Science (MS) program, offered jointly by Geisel School of Medicine at Dartmouth and Thayer, is designed for students intending 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.

Prerequisites

Candidates must hold an undergraduate degree in engineering from an accredited institution and meet the entrance requirements of each school. MS+MD candidates must have applied and been accepted to both Geisel School of Medicine and Thayer School of Engineering. MD students from Geisel typically apply to Thayer 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.

Matching Interests to Faculty

MS+MD students typically are funded through a professor’s sponsored research or a fellowship throughout their studies at Thayer School. Therefore, MD students interested in pursuing particular areas of engineering research should contact Thayer faculty for an initial conversation about research opportunities. During the application process, applicants should indicate all areas of interest in order to be considered for the widest possible range of opportunities.

Typical Academic Sequence

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 three terms in residence at Thayer.

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

ENGINEERING REQUIREMENTS FOR JOINT MD+MS DEGREE

REQUIRED COURSEWORK		
Applied Mathematics **(Choose 1)**	ENGS 91 Numerical Methods in Computation	1 course
	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	
Engineering Courses **(Choose 2)**	ENGS 110 Signal Processing	2 courses
	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	
Engineering Electives **(Choose 3)**	Select 3 additional graduate engineering courses	3 courses
REQUIRED RESEARCH & THESIS		
Research and Written Thesis	Research that demonstrates a depth of knowledge in a specific field of engineering research or design that leads to a written thesis.	
Oral Defense	An oral defense of the thesis	

Doctor of Philosophy (PhD)

engineering.dartmouth.edu/graduate/phd

Dartmouth engineering PhD students acquire engineering and technical depth in their chosen focus area while also gaining breadth of knowledge in related fields. The PhD program not only provides students with opportunities to gain expertise in engineering, but also in "power-skills" such as problem-solving, communications, risk-taking, leadership, to generate research and innovations with human-centered impact.

Prerequisites

The foundation for doctoral work is undergraduate preparation in science, mathematics, and engineering principles. Applicants must hold a bachelor's and/or a master's degree from an accredited institution to be considered for the program. Students admitted to the program who are not prepared to complete the first-year requirements are advised to enter the MS program and petition 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.

Program Areas

Dartmouth offers a diversity of concentrations with collaborative synergies between engineering disciplines. Graduate students are expected to propose a plan of study that supports their interests on a path unconstrained by disciplinary boundaries. Both faculty and students draw from these multiple areas of expertise for maximum human-centered impact:

- Biological and Chemical Engineering
- Biomedical Engineering
- Electrical and Computer Engineering
- Energy Engineering
- Materials Science and Engineering
- Mechanical, Operations and Systems Engineering

PhD Innovation Program / PhD Innovation: Surgical Innovation

Students interested in entrepreneurship can augment their program with the PhD Innovation or the PhD Innovation: Surgical Training Track programs, which adds courses that address technology business practices and the art of moving research discoveries to market. PhD Innovation Fellows in both programs are required to fulfill all requirements of the regular PhD program, as well as additional coursework, industry internships, and other requirements specific to the program.

Advisors

Faculty advisors aid PhD students in developing their course of study, which is submitted to and approved by Thayer's Graduate Programs Committee during the student's first term of residency.

Program of Study and Research

The PhD 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 in applied mathematics and engineering, as well as take on a multi-year research project, usually as part of a larger multidisciplinary project. 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. PhD students work closely with their faculty advisor who is sponsoring their research, to identify and further define their research focus.

Residency Requirements and Program Duration

Students in the PhD program are expected to spend at least nine terms in residence, three of which will take place after successfully completing the oral qualifying examination. Students who are registered and enrolled in two or more courses a term are considered full-time and as being "in residence." Students typically take about four to five years to complete the requirements for the PhD.

PhD: PROGRAM OF STUDY

The PhD 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 shown below. Students with prior graduate credits may transfer up to five courses to count toward this requirement. In addition to engineering and applied mathematics, PhD students also participate in the required seminars and workshops.

REQUIRED COURSEWORK		
Applied Mathematics (Choose 2 or more)	ENGS 91 Numerical Methods in Computation	2 or more courses
	ENGS 92 Fourier Transforms and Complex Variables	
	ENGS 93 Statistical Methods in Engineering	
	ENGS 100 Methods in Applied Mathematics I	
	ENGS 104 Optimization Methods for Engineering Applications	
	ENGS 105 Computational Methods for Partial Differential Equations I	
	ENGS 106 Numerical Linear Algebra	
Engineering Breadth (Choose 2 or more)	Courses leading to acquiring breadth of knowledge in Engineering Sciences.	2 or more courses
Engineering Specialization (Choose 4)	Courses in the student's area of research, chosen to increase depth of knowledge and expertise. These courses should be selected in concert with the thesis advisor.	4 courses
REQUIRED SEMINARS & WORKSHOPS		
Professional Skills Development	ENGG 195 Seminar on Science, Technology, and Society	4 terms
	ENGG 197 PhD Professional Workshops	1 term
	ENGG 198 Research-in-Progress Workshop	Annually

PhD: FIRST-YEAR 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 two additional Thayer faculty members. This group helps each student develop a first-year program of study, which the student submits to the Thayer Registrar 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)

PhD: FULL PROGRAM PLAN

During the student's first term, the faculty helps the student develop a full program plan to fulfill the PhD requirements, which the student submits to the Thayer Registrar before the beginning of the second term. 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
- ENGG 197 PhD Professional Workshops
- ENGG 198 Research-in-Progress Workshop

ANNUAL PhD ADVISOR MEETING

At the end of each year, students meet with their faculty advisor to review grades, goals, achievements and future plans in research, formal coursework, and extracurricular activities. This meeting, and a corresponding written report, is required for every year that a student remains registered in the PhD program.

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 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.

Students who are not progressing in a normal manner are transferred to the MS program with the understanding that they may later request to be reconsidered as PhD candidates.

PhD: CANDIDACY PHASE

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
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
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
Specialization	Mastery of knowledge in the chosen area of research	Presentation of a thesis proposal *and* a program of study
Professional competence	Ability to develop resources in chosen area of research	ENGG 197 PhD Professional Workshops
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

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 exam is flexible.

The student prepares a description of the planned exam, obtains signatures of the advisor, committee members, and the director of the MS and PhD programs, and submits this to the Thayer Registrar at least one month prior to the exam date. The examination committee consists of four members — the Chair plus three Dartmouth faculty examiners, with at least two of the examiners from Thayer. A Thayer faculty member other than the student's advisor chairs the committee. This chair is assigned by the director of the MS and PhD 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 three 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 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:

- A set of courses, taken for credit, outside or secondary to the candidate's principal area of specialization
- A focused set of courses, taken for credit, which creates a secondary emphasis in specialization and may involve independent study or research
- 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. Students who do not pass may be permitted to take the oral examination—one time only—within the following three months.
- 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 three months.

Specialization (Thesis Proposal)

The candidate demonstrates mastery of an area of specialization by writing and defending 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 defense of the thesis proposal.

The PhD examination committee consists of a minimum of three full-time Dartmouth faculty members of which a minimum of two must be from Thayer (including the dissertation advisor) and an external member with a faculty equivalent research appointment outside of Dartmouth is optional, but not required. The external member may participate in meetings in person or via video conference.

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

Two weeks before the defense, 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 two 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 three full-time Dartmouth faculty members of which a minimum of two must be from Thayer (including the dissertation advisor) and 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:

REQUIREMENTS	DEMONSTRATED BY
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. 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. 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.
Paper	Elements of the research accepted for publication with the candidate as first author.

Dissertation Archiving

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

PhD Career Development

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

Engineering Management

PhD students interested in administration and management may obtain an Engineering Management Certificate by completing any 3 of the following courses:

- ENGM 180 Accounting and Finance
- ENGM 181 Marketing
- ENGM 183 Operations Management
- ENGM 185 Topics in Manufacturing Design and Processes
- ENGM 186 Technology Project Management
- ENGM 188 Law for Technology and Entrepreneurship
- ENGM 190 Platform Design, Management, and Strategy
- ENGM 191 Product Design and Development

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

Engineering Design & Development

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

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

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.

Teaching

Interested PhD students may serve as teaching assistants for courses that have a problem session, tutorial, or laboratory component. In special cases, a student may participate in the design and development of a special topics course or a laboratory exercises for a lecture course. Students become eligible for these positions following completion of the oral qualifying exam. More formalized teacher training, offered through the Dartmouth Center for the Advancement of Learning, is also available to engineering PhD students.

PhD Innovation Program

engineering.dartmouth.edu/graduate/phdi

Dartmouth's PhD Innovation Program, offered through both Thayer and Guarini School for Graduate and Advanced Studies, is the nation's first doctoral-level innovation program aimed at providing PhD students engaged in enterprising research the skills and support necessary to translate their work into the commercial sphere. PhD Innovation Fellows have spun innovations developed from their research into start-up companies, a new division of an established company, or a government or non-profit enterprise.

Thayer School of Engineering offers a **PhD Innovation Program** for students specializing in a variety of engineering disciplines and a more focused track for students interested in surgical innovation through the **PhD Innovation: Training for Surgical Innovation Program (TPSI).**

PROGRAM COMPARISON:

PhD vs. PhD Innovation vs. PhD Innovation: TPSI

	PhD	PhD INNOVATION	PhD INNOVATION: TPSI
Total Coursework	11–13 courses total (6 courses during the first year)	15–17 courses total (6 courses during the first year)	15–17 courses total (6 courses during the first year)
Engineering Specialization	4 courses (Year 1)	4 courses (Year 1)	4 courses (Year 1)
Applied Mathematics	2 or more courses (Year 1)	2 or more courses (Year 1)	2 or more courses (Year 1)
Professional Skills Development	3 courses	3 courses	3 courses
Engineering Breadth Electives	2 or more courses		
Innovation Elective		1 or more course	1 or more course
Innovation Core		4 courses	4 courses
Surgical Rotation & Training			3 terms (Year 2)
Innovation Internship		Full-time industry internship for a period of up to 3-6 months.	Full-time industry internship for a period of up to 3-6 months.
Original Research & Dissertation	Required	Required	Required

Residency Requirements and Program Duration

Students in the PhD Innovation Program are expected to spend at least nine terms in residence, three of which will take place after successfully completing the oral qualifying examination. Students who are registered and enrolled in two or more courses a term are considered full-time and as being "in residence." Students typically take up to five years to complete the requirements for the PhD Innovation Program.

PHD INNOVATION PROGRAM

engineering.dartmouth.edu/graduate/phd

Program Overview

PhD Innovation Program builds on the foundational and specialized coursework of the regular engineering PhD program and provides coursework, mentoring, resources, and support necessary for students to know how to bring their research to market. PhD Innovation Fellows take additional coursework in business, technology innovation, and entrepreneurship, and spend up to six months at an industry internship.

Eligibility and Admission

Applicants must meet all prerequisites and requirements for the standard PhD degree program. New PhD applicants, as well as current engineering PhD and MD+PhD students are eligible to apply to the PhD Innovation Program. These students are advised to consult with their faculty advisor and **Professor Eric Fossum**, Director of the PhD Innovation Program, prior to applying.

Requirements

PhD Innovation Fellows must 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.

REQUIREMENTS FOR PhD INNOVATION		
All coursework, professional skills development, original research, and dissertation requirements for the regular PhD program.		
ADDITIONAL REQUIREMENTS		
Innovation Core	ENGM 180 Accounting and Finance	4 courses
	ENGM 187 Technology Innovation and Entrepreneurship (typically taken during 2nd year)	
	ENGM 188 Law for Technology and Entrepreneurship (or equivalent course)	
	ENGG 321 Advanced Innovation and Entrepreneurship (typically taken during 4th year)	
Innovation Elective* **(Choose 1 or more)**	One or more graduate-level technical courses outside the student’s area of expertise.	1 or more courses
Industry Internship	ENGG 300 Enterprise Experience Project: To gain first-hand familiarity with how technology innovation is implemented in companies, students will arrange a full-time internship for a period of three to six months. The company must be engaged in some facet of technology innovation. Under special circumstances, students may be allowed to work on their own startup. Students with significant prior experience in a company may request waiver of the internship requirement.	3-6 months

* The Innovation Elective requirement is in place of the Engineering Breadth course requirement in the standard PhD program.

PhD INNOVATION: TRAINING PROGRAM IN SURGICAL INNOVATION

engineering.dartmouth.edu/graduate/phdi/tpsi

Program Overview

The Training Program in Surgical Innovation (TPSI) is the first discipline-specific track within the PhD Innovation Program and offers students additional opportunities at Dartmouth-Hitchcock's Center for Surgical Innovation (CSI). TPSI 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 addressing unsolved problems in surgery, rather than leaving them to chance or trial-and-error, and provides students with the skills and training necessary to pursue careers in biomedical engineering innovation and entrepreneurship in industry as well as academia.

PhD Innovation Fellows in the Surgical Innovation track fulfill the requirements for the standard PhD, the additional coursework requirements for the PhD Innovation Program, as well an internship in surgical setting.

Eligibility and Admission

Applicants must meet all prerequisites and requirements for the regular PhD degree program. Trainees are selected from applicants to Dartmouth's PhD Innovation Program, who have specifically expressed an interest in the Training Program for Surgical Innovation. Current Dartmouth engineering PhD students may also apply to TPSI during their first or second year of the regular PhD program. These students are advised to consult with their faculty advisor, **Professor Keith Paulsen**, and **Professor Eric Fossum** prior to applying.

Faculty Mentors

The program provides faculty mentors in biomedical engineering, surgical translation, and innovation and entrepreneurship. Each trainee is assigned three mentors — one from each area of expertise — for guidance through the program.

Surgical Innovation Rotation and Training

As part of the requirements for TPSI, students also engage in immersive learning in a variety of medical and surgical settings, over the course of three 10-week terms — for a full academic year — through the ENGG 325: Introduction to Surgical Innovation course. The rotation and training experience is aimed at providing students the opportunity to observe, understand, and identify opportunities for innovation that can lead to improved patient outcomes or surgical procedures.

Fall term begins with a general surgery rotation, where TPSI students work alongside third-year medical students and surgical residents and participate in rounds, medical student case discussion, and observe at least one surgical procedure and one outpatient clinic patient encounter with a proctor or an assigned surgeon colleague.

During the winter term, students focus on a subspecialty of their choice, such as minimally invasive general surgery, oncologic surgery, otolaryngology, anesthesiology, neurosurgery or orthopedic surgery.

In the spring, students select a clinical mentor and an engineering mentor to guide development of a research proposal. The research 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.

Requirements

Students must satisfy all requirements of the PhD Innovation Program — technical proficiency, technical breadth, specialization, professional competence, original research, and innovation skills development — plus specific training tailored to the surgical setting, including an internship for surgical innovation.

REQUIREMENTS FOR PhD INNOVATION: TRAINING PROGRAM FOR SURGICAL INNOVATION		
All coursework, professional skills development, original research, and dissertation requirements for the regular PhD program, plus all additional requirements for the PhD Innovation Program.		
ADDITIONAL REQUIREMENTS		
Surgical Innovation Rotation & Training	ENGG 325 Introduction to Surgical Innovation: Students engage in immersive, experiential learning in a variety of medical and surgical settings, over the course of three 10-week terms (a full academic year) and work alongside third-year medical students and surgical residents. **Fall term:** General surgery rotation **Winter term:** Surgical subspecialty of the student's choice **Spring term:** Surgical research rotation	3 terms

Residency Requirements and Program Duration

Students in the PhD Innovation: TPSI are expected to spend at least nine terms in residence, three of which will take place after successfully completing the oral qualifying examination. Students who are registered and enrolled in two or more courses a term are considered full-time and as being "in residence." Students typically take up to five years to complete the requirements for the PhD Innovation: TPSI.

Doctor of Medicine (MD) + Doctor of Philosophy (PhD)

geiselmed.dartmouth.edu/mdphd
engineering.dartmouth.edu/graduate/md-phd

The Doctor of Medicine (MD) and Doctor of Philosophy (PhD) Program combines the medical curriculum of Geisel School of Medicine with the PhD engineering curriculum at Thayer. The MD-PhD program provides students with extensive training in both medicine and engineering to position graduates for both clinical practice and research.

Program Overview

The program is organized to effectively and efficiently pursue both degrees, while also developing an understanding of the health care system as a whole. Along with courses at Geisel, students train in laboratories with Thayer faculty, and are paired with mentors from across Dartmouth, including Thayer, Geisel, and clinicians from Dartmouth-Hitchcock Medical Center.

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 from an accredited institution to be considered for admission to the MD-PhD program. Students must apply to both Thayer School of Engineering and Geisel School of Medicine, indicating their specific interest in the MD-PhD program.

Requirements

MD-PhD students must fulfill all of the degree requirements for both the MD program at Geisel and the PhD program at Thayer, including research and dissertation requirements.

Course of Study

There are three major phases of study. Broadly stated, students spend the initial phase at Geisel, the second phase at Thayer fulfilling the requirements for the PhD, then the final phase at Geisel to complete the requirements for the MD.

Initial Medical Phase (Years 1 and 2)	Geisel School of Medicine ● Complete M1 and M2 requirements ● Up to three 8-week laboratory rotations
First-Year PhD (Year 3)	Thayer School of Engineering ● 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 (Year 4)	Thayer School of Engineering ● Oral examination ● Completion of additional graduate courses ● ENGG 195: Seminar on Science, Technology, and Society (two terms) ● ENGG 197: PhD Professional Workshops ● ENGG 198: Research-in-Progress Workshop ● Thesis proposal and dissertation research
Final PhD Year (Year 5)	Thayer School of Engineering ● Dissertation research ● Completion of thesis defense
Final MD Phase (Years 6 and 7)	Geisel School of Medicine ● Complete M3 and M4 requirements

Residency Requirements and Program Duration

MD-PhD candidates are required to be in residence for a minimum of six terms, including two terms of participation in ENGG 195: Seminar on Science, Technology, and Society and one term of ENGG 198: Research-in-Progress Workshop. Students who are registered and enrolled in two or more courses a term are considered full-time and as being “in residence.” Students in this program earn the PhD and MD degrees simultaneously, after typically seven to eight years of study.

Graduate Admissions, Financial Aid, and Funding

engineering.dartmouth.edu/apply

MEM, MEng, MS, and PhD Admissions

engineering.dartmouth.edu/apply

Students should refer to Thayer's website (engineering.dartmouth.edu/apply) for the most current application and admissions information for each degree program. Students should review all information and **apply online** by the appropriate deadlines.

Joint degree applicants to MD+MS or MD+PhD programs should review all application and admissions information for both Thayer School of Engineering and Geisel School of Medicine and apply by the appropriate deadlines. Joint degree applicants to MEM+MBA programs should review all application and admissions information for both Thayer School of Engineering and Tuck School of Business and apply by the appropriate deadlines.

Graduate Tuition & Expenses

Tuition covers the cost of instruction, student support services, the use and maintenance of our instructional facilities, and health care service through Dartmouth's Health Center. Information about tuition, fees, and total estimated annual expenses for the current academic year is available on Thayer and Dartmouth websites (dartmouth.edu/finance/tuition/billing_paying_tuition/tuition_fees.php).

Graduate Financial Aid

Full-time students 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. Financial aid and scholarship assistance is provided on an annual basis. Please visit the website for most current financial aid information.

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MEM Financial Aid

mem.dartmouth.edu/financial-aid

Need-based financial aid is available to all eligible full-time students (international and domestic). Contingent upon satisfactory performance and academic progress, all MEM students are eligible for need-based financial aid. To be considered for financial aid, prospective students must request financial aid while submitting their application.

MEng Financial Aid

engineering.dartmouth.edu/graduate/meng#tuition-expenses

Need-based, partial tuition scholarships to eligible MEng students, capped at 40 percent of tuition. Students must submit financial aid materials at the time of application. Late applications for financial aid may be accepted, but awards will be capped at 20 percent based on budget availability.

MS Funding

engineering.dartmouth.edu/graduate/ms#tuition-expenses

MS students are funded through research grants and faculty funding, which begins with the initiation of thesis research. Funding covers tuition, stipend, and health insurance, but does not cover the six graduate courses that MS students must have completed, either at Dartmouth or a prior institution, before commencing thesis work. Qualified students may be awarded stipends through positions as research or teaching assistants. Graduate research assistantships normally carry an award of full tuition, a monthly stipend, and credit toward medical insurance if purchased through the College. In addition, a number of scholarship, fellowship and grant programs offer financial awards that are also available to MS students.

PhD Funding

engineering.dartmouth.edu/graduate/phd#tuition-expenses

PhD students typically enter with full funding support from either a Graduate Research Assistantship (GRA) or an external fellowship. GRAs, funded by contract research, are available to well-qualified candidates enrolled in degree programs with thesis requirements. Most PhD funding includes full tuition cost coverage plus a monthly stipend. GRAs also include health care coverage for those who opt for college insurance. Students who obtain an external fellowship that fully funds their PhD—such as from NSF, DOD, NASA, or DOE—will receive an additional yearly stipend from Thayer for the duration of their PhD. In addition, a number of scholarship, fellowship and grant programs offer financial awards that are also available to PhD students.

PhD Innovation Fellowship

engineering.dartmouth.edu/graduate/phdi#program-comparison

PhD Innovation Fellows receive up to five years of full financial support. The first year of funding draws from either the graduate research assistantship or an external fellowship. During the second year, students are funded 50/50 through Thayer and PhD Innovation Program fellowships. In the third year, students are funded 50/50 by Thayer and PhD Innovation fellowships and receive up to $10,000 unrestricted grant funding, independent of the faculty advisor's funded research program, to support their entrepreneurial studies and pursuits. In the fourth and fifth years, students are funded entirely through the PhD Innovation fellowship and continue to receive up to $10,000 unrestricted grant funding.

Policies & Regulations

Registration and Check-In

All students intending to be in residence must check-in at the beginning of each term through an online check-in process. This practice lets the faculty and administration know who is in residence for the new term and facilitates identifying individual students who may require additional assistance.

Students may begin check-in the day before classes begin and until the end of the third day of class, without a $50 penalty.

After the third day until the 10th day of class, a $50 penalty will be assessed for late check-ins. Students, with good reason, may petition the Registrar for waiver of this charge. All financial accounts with Dartmouth 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

During the first five class days of a term, students may add, drop, or exchange courses online using DartHub, with no prior approval. When possible, students are strongly encouraged to arrange their course load during this period.

During the second five class days of a term, a student may add or exchange courses only with the approval of the instructor of the intended new course.

After this period, and until 10 class days before the last class of the term, students may withdraw from a course at their own discretion.

Withdrawal from Courses

Students may withdraw from a course at their own discretion up until 10 class days before the last class of the term. The student must notify the instructor, as a courtesy, of their intention to withdraw and submit the withdrawal to the Registrar on or before the withdrawal deadline indicated for each term. The course remains on the student's transcript with the notation "W" for "Withdrew."

During the last 10 days of classes in the term until the final examination begins, students must petition to withdraw from a course. Most petitions will not be approved, except in the most extreme medical or other circumstances. Once the final examination period has begun, it will be assumed that students intend to complete their courses and no course withdrawal requests will be accepted.

Withdrawal from 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 their candidacy must petition the dean or directors of their degree program in writing for readmission to the program.

Refund Policy

Refunds for students who withdraw after tuition has been paid, but **prior to registration and the first day of classes**, will be 100% of tuition. After the first day of classes, refunds will be calculated as follows:

- 90% of tuition for withdrawal during the **first week of the term**
- 75% of tuition for withdrawal during the **second and third weeks of the term**
- 50% of tuition for withdrawal during the **fourth week of the term**
- 25% of tuition for withdrawal during the **fifth week of the term**
- No tuition refunds will be issued after the fifth week of the term.

Other charges, such as payments to the Dartmouth Student Group Health Plan, are non-refundable. Other miscellaneous fees and charges, including student activity fees, are non-refundable if the student withdraws after registration and the first day of classes. All requests for refunds must be submitted in writing to:

Campus Billing
6132 McNutt Hall, Room 103
Hanover, NH 03755
Tel. +1 (603) 646-3230
Fax. +1 (603) 646-3455
campus.billing@dartmouth.edu

Any balance due to the student, after adjustments are made, will be paid within 30 days. In any instance where it is felt that individual circumstances may warrant an exception to the Refund Policy, the student may appeal in writing to the Controller


DARTMOUTH
ENGINEERING
1867
Watchhouse

Undergraduate Courses

Undergraduate Courses

engineering.dartmouth.edu/courses/undergraduate

The undergraduate program in Engineering Sciences offers foundational, core, and advanced courses in a variety of engineering disciplines. In addition, Thayer School of Engineering at Dartmouth offers introductory courses, with no or few prerequisites, for non-majors or first-year students exploring engineering. Majors and modified majors may focus on a specific engineering discipline through electives. Many students pursue additional coursework, beyond what is required for the Bachelor of Arts (AB) degree, to earn a Bachelor of Engineering (BE) or higher at Dartmouth.

Guide to Undergraduate Course Listings

Course Prefix

The prefix before the course number—ENGS or ENGG—provides context for the degree requirements that specific courses satisfy and the type of credit granted.

PREFIX	DESCRIPTION
ENGS	ENGS courses can be used for credit toward the AB degree and to satisfy requirements for the Engineering Sciences major.
ENGG	ENGG courses, which are generally graduate-level courses, can be used for credit toward the AB degree but do not satisfy requirements for the Engineering Sciences major.

Course Numbers

Undergraduate engineering courses are numbered 1 to 99, with upper-level courses requiring prerequisite coursework. Engineering Science majors may take graduate courses (ENGS or ENGG courses number above 100) for which they are qualified. Not all graduate courses, however, can be used to satisfy the AB and/or Engineering Sciences major requirements.

NUMBER	DESCRIPTION
1-19	Courses in Engineering Sciences and Human-Centered Design that do not require prerequisite coursework.
20-79	Core Engineering Sciences courses, with required prerequisites in Math,
80-89	Engineering seminars, thesis, independent study, or honors coursework.
90-99	Advanced undergraduate-level courses with significant design, research, or project work.

Distributive Codes

All students pursuing the AB are required to take courses that fulfill distributive and world culture requirements. Engineering courses at Thayer fulfill a range of distributive code requirements as noted in the course listings.

INT International or Comparative Study
QDS Quantitative or Deductive Science
SCI Natural and Physical Science (without Lab)
SLA Natural and Physical Science (with Lab)
TAS Technology or Applied Science (without Lab)
TLA Technology or Applied Science (with Lab)
TMV Systems, Traditions of Thought, Meaning and Value

Terms Offered

Information about the terms when courses will be offered reflect the plan for the next two academic years. Not all courses listed are offered each year, and course availability is subject to change. For the most current information, consult the course descriptions and schedules on the website: engineering.dartmouth.edu/courses/undergraduate.

2021-2022		2022-2023		2023-2024	
21F:	Fall 2021	**22F:**	Fall 2021	**23F:**	Fall 2023
22W:	Winter 2022	**23W:**	Winter 2022	**24W:**	Winter 2024 (if available)
22S:	Spring 2022	**23S:**	Spring 2022	**24S:**	Spring 2024 (if available)
22X:	Summer 2022	**23X:**	Summer 2022	**24X:**	Summer 2024 (if available)

Class Schedule and Time Periods

Course times are *not listed* in the printed guide as they are subject to change. The number or number-letter combination represents the day(s) of the week and the time period in which classes are offered. The X-period time set aside for instructors to use as needed. For some courses, the X-period is an additional class session. For the most up-to-date course descriptions, offerings, time and location, and instructor information, please visit the Dartmouth Timetable of Class Meetings (oracle-www.dartmouth.edu/dart/groucho/timetable.main) or Thayer's undergraduate course listings online (engineering.dartmouth.edu/courses/undergraduate).

CLASS*	DAY(S)	TIME	X-PERIOD	DAY	TIME
8S	MTuThF	7:45–8:35 a.m.	**8SX**	W	7:45–8:35 a.m.
8L	MWF	7:30–8:35 a.m.	**8LX**	Th	7:45–8:35 a.m.
9S	MTuThF	9:05–9:55 a.m.	**9SX**	W	9:05–9:55 a.m.
9L	MWF	8:50–9:55 a.m.	**9LX**	Th	9:05–9:55 a.m.
10	MWF	10:10–11:15 a.m.	**10X**	Th	12:15–1:05 p.m.
10A	TuTh	10:10 a.m.–12:00 p.m.	**10AX**	F	3:30–4:20 p.m.
11	MWF	11:30–12:35 p.m.	**11X**	Tu	12:15–1:05 p.m.
12	MWF	12:50–1:55 p.m.	**12X**	Tu	1:20–2:10 p.m..
2	MWF	2:10–3:15 p.m.	**2X**	Th	1:20–2:10 p.m.
2A	TuTh	2:25–4:15 p.m.	**2AX**	F	4:35–5:25 p.m.
3A	MW	3:30–5:20 p.m.	**3AX**	M	5:30–6:20 p.m.
3B	TuTh	4:30–6:20 p.m.	**3BX**	W	5:30–6:20 p.m.
6A	MW	6:30–8:20 p.m.	**6AX**	Tu	6:30–7:20 p.m.
6B	W	6:30–9:30 p.m.	**6BX**	Tu	7:30–8:20 p.m.

* This reflects the class schedule, as of Fall 2021. For the most current information, consult Dartmouth's Weekly Class Diagram on Dartmouth's Office of the Registrar's website

Course Cancellation Policy

Please be advised that any listed course may be canceled if the enrollment is fewer than five students.

Undergraduate Courses by Category

CATEGORY	COURSES
Courses for Non-Majors	ENGS 1.01 Mathematical Concepts in Engineering ENGS 2 Integrated Design: Engineering, Architecture, and Building Technology ENGS 3 Materials: The Substance of Civilization ENGS 4 Technology of Cyberspace ENGS 5 Healthcare and Biotechnology in the 21st Century ENGS 6 Technology and Biosecurity ENGS 7.02 Climate Change ENGS 7.05 Contemporary and Historical Perspectives on Medical Imaging ENGS 7.06 Sustainability Revolution ENGS 7.07 Science, Media & Literature ENGS 8 Materials in Sports Equipment ENGS 9 Everyday Technology ENGS 10 The Science and Engineering of Digital Imaging ENGS 11 The Way Things Work - A Visual Introduction to Engineering ENGS 12 Design Thinking ENGS 13 Virtual Medicine and Cybercare ENGS 15 Undergraduate Investigations in Engineering ENGS 15.01 Senior Design Challenge I ENGS 15.02 Senior Design Challenge II ENGS 15.03 The Ecosystem for Bio-Innovation ENGS 15.04 Computing Before Electronics ENGS 16 Biomedical Engineering for Global Health ENGS 17 Making Music: The Art, Science, and Symbolism of Musical Instruments ENGS 18 System Dynamics in Policy Design and Analysis ENGS 19.01 Future of Energy Systems
Courses for Engineering Sciences Majors, Modified Majors, and Minors (continued)	**Prerequisite** ENGS 20 Introduction to Scientific Computing **Common Core Courses** ENGS 21 Introduction to Engineering ENGS 22 Systems ENGS 23 Distributed Systems and Fields **Distributive Core Courses** ENGS 24 Science of Materials ENGS 25 Introduction to Thermodynamics ENGS 26 Control Theory ENGS 27 Discrete and Probabilistic Systems ENGS 28 Embedded Systems **Gateway Courses** ENGS 30 Biological Physics ENGS 31 Digital Electronics ENGS 32 Electronics: Introduction to Linear and Digital Circuits ENGS 33 Solid Mechanics ENGS 34 Fluid Mechanics ENGS 35 Biotechnology and Biochemical Engineering ENGS 36 Chemical Engineering ENGS 37 Introduction to Environmental Engineering

Undergraduate Courses by Category (continued on next page)

Undergraduate Courses by Category (continued from previous page)

(continued) **Courses for Engineering Sciences Majors, Modified 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 52 Introduction to Operations Research ENGS 56 Introduction to Biomedical Engineering ENGS 57 Intermediate Biomedical Engineering ENGS 58 Introduction to Protein Engineering ENGS 59 Basic Biological Circuit 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 in Engineering Sciences 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 ENGG 113 Image Visualization and Analysis ENGS 137 Molecular and Materials Design using Density Functional Theory
Courses for Human-Centered Design Minor and Modified Major	ENGS 12 Design Thinking ENGS 15.01 Senior Design Challenge I ENGS 15.02 Senior Design Challenge II ENGS 18 System Dynamics in Policy Design and Analysis ENGS 75 Product Design

Undergraduate Course Descriptions

For the most up-to-date course descriptions, offerings, time and location, and instructor information, please visit: engineering.dartmouth.edu/courses/undergraduate.

ENGS 1.01 Mathematical Concepts in Engineering

Offered: 21F

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.
No prerequisites
Dist: TAS
Instructor: Bonfert-Taylor

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

Offered: 22W, 22X, 23W, 23X

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 prerequisites
Dist: TAS
Instructor: Wilson

ENGS 3 Materials: The Substance of Civilization

Offered: 22W, 23W, 23W

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 50 students per section.
No prerequisites
Dist: TAS
Instructors: Bish, Lasky

ENGS 4 Technology of Cyberspace

Offered: 21F, 22F, 23F

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
Dist: TAS
Instructors: Taylor

ENGS 5 Healthcare and Biotechnology in the 21st Century

Offered: 22S, 23S

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 prerequisites

Dist: TAS

Instructors: Robbie, Rosen

ENGS 6 Technology and Biosecurity

Offered: 22S, 23S

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 prerequisites

Dist: TAS

Instructor: Hoyt

ENGS 7.02 Climate Change (First-Year Seminar)

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.

No prerequisites

Dist: TAS

ENGS 7.05 Contemporary and Historical Perspectives on Medical Imaging (First-Year Seminar)

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.

No prerequisites

Dist: TAS

ENGS 7.06 Sustainability Revolution (First-Year Seminar)

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 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.
No prerequisites
Dist: TAS

ENGS 8 Materials in Sports Equipment

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 40 students.
No prerequisites
Dist: TAS

ENGS 9 Everyday Technology

Offered: 22S, 23S
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 prerequisites
Dist: TLA
Instructors: Davis

ENGS 10 The Science and Engineering of Digital Imaging

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 prerequisites
Dist: TAS

ENGS 11 The Way Things Work: A Visual Introduction to Engineering
Offered: 22W, 23W
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 prerequisites
Dist: ART
Instructor: Macaulay

ENGS 12 Design Thinking
Offered: 21F, 22W, 22S, 22F, 23W, 23S, 23F
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 prerequisites
Dist: TAS
Instructors: Korsunskiy, Robbie, Steinhauer

ENGS 13 Virtual Medicine and Cybercare
Offered: 21F, 22F, 23F
There is a revolution in technology that is occurring in health care. This new technology will dramatically change how healthcare 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 prerequisites
Dist: TAS
Instructors: Korsunskiy, Robbie, Steinhauer

ENGS 15 Undergraduate Investigations in Engineering
Offered: 21F, 22W, 22S, 22X, 22F, 23W, 23S, 23X, 23F
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.
Prerequisites: 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

Offered: 22W, 23W

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 prerequisites

Dist: TAS

Instructor: Korsunskiy

ENGS 15.02 Senior Design Challenge II

Offered: 22S, 23S

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 prerequisites

Dist: TAS

Instructor: Korsunskiy

ENGS 15.03 The Ecosystem for Bio-Innovation

We are living through biology's century: global pandemics; $100 genomes; bio-reactor beef; plastic-eating engineered microbes...and we still have 80 years to go. This course is built around the basic idea that biotechnology is changing the world, but will only reach its greatest potential—technologically, economically, ethically—if we learn to guide it as a complex ecosystem of interdependent actors. Biotech hubs thrive where there is a dense milieu of intellectual and financial capital from top universities, academic medical centers, entrepreneurs, and venture capital. This course aims to ensure that future leaders—physicians, scientists, journalists, lawyers, financiers, patients, legislators—understand the ways that scientific advances, innovation policy, and entrepreneurship feed one another. Taught by a biotech venture capital investor, this is an interdisciplinary course designed to empower students with the context and confidence to go deeper than news headlines that fail to see both the 'forest' and the 'trees'. The term will unfold in a cumulative manner. We begin with a diagnosis and overview of the Ecosystem for Bio-Innovation, and then go deeper into the institutions and players that cross-pollinate within this ecosystem, focusing on healthcare (e.g. mRNA vaccines, genetic disease treatments) while making note of biotechnology's far broader impact on our society and planet. Each week of the course will focus on one theme, while also introducing new intellectual frameworks, plus real-world cases to help concretize key concepts. We will bring material to life through a combination of lecture, Socratic learning, student projects, guest speakers, and in-class debates, always infusing our time together with a sense of the scientific, economic, political, and ethical choices at stake. Final projects will allow students to critically apply coursework toward a cutting-edge area of biotechnology.

No prerequisites

Dist: TAS

Instructor: Cooper

ENGS 15.04 Computing Before Electronics
Offered: 22W
In this course we explore the computational techniques by which mankind survived and thrived before the advent of the integrated circuit and the electronic calculator. From the commerce of early civilizations until the last third of the 20th century, there was a progression of mechanical calculating gadgets, some simple – some quite ingenious and complex. Among these we will study slide rules, planimeters, integrators, digital adding machines, nomographs, and other special charts and graphical techniques. We will also cover celestial navigation, which in its day was a particularly important application of calculation. Laboratory sessions will give students direct experience using antique and period calculating instruments, plus the opportunity to create their own calculating devices.
No prerequisites
Dist: TLA
Instructor: Frost

ENGS 16 Biomedical Engineering for Global Health
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 prerequisites
Dist: TAS

ENGS 17 Making Music: Art, Science, and Symbolism of Musical Instruments (Identical to MUS 17.04/COCO 20)
A hands-on course in which students working in groups build and assemble simple musical instruments with the aim of understanding how materials, technologies, craftsmanship, and cultural knowledge interact in the conception, design, and production of diverse instruments around the world. Merging the methodologies of materials science and engineering with the approaches of arts and humanities, the course explores from an interdisciplinary perspective the social meanings and powers ascribed to musical instruments, and the way that instruments have come to function as potent symbols of personal, cultural, and political identity.
No prerequisites
Dist: INT

ENGS 18 System Dynamics in Policy Design and Analysis
Offered: 22W, 23W
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.
Prerequisites: MATH 3
Dist: TAS
Instructor: Peterson

ENGS 19.01 Future of Energy Systems

Offered: 22S, 23S

Energy production, distribution, and use is central to human activity. In many quarters, there is growing appreciation for the nexus among energy, climate change, the environment, and economic development. This course will focus on futures of energy as they impact, and are impacted by, these drivers. The course uses model-based approaches to develop global-scale energy scenarios and to explore the potential evolution of current and potential energy options in both localized and global settings.

No prerequisites

Dist: TAS

Instructor: Peterson

ENGS 20 Introduction to Scientific Computing

Offered: 21F, 22W, 22S, 22F, 23W, 23S, 23F

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

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

Dist: TAS

Instructors: Bonfert-Taylor, Seroussi, Shepherd

ENGS 21 Introduction to Engineering

Offered: 21F, 22W, 22S, 22F, 23W, 23S, 23F

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.

Prerequisites: MATH 3 or equivalent

Dist: TAS

Instructors: May, Murnane, Snyder

ENGS 22 Systems

Offered: 21F, 22W, 22S, 22X, 22F, 23W, 23S, 23X, 23F

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.

Prerequisites: MATH 13, PHYS 14, and ENGS 20

Dist: TLA

Instructors: Seroussi, Scheideler, Zhang

ENGS 23 Distributed Systems and Fields

Offered: 21F, 22W, 22S, 22F, 23W, 23S, 23F

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.

Prerequisites: ENGS 22, or equivalent

Dist: TAS

Instructors: Österberg, Sullivan

ENGS 24 Science of Materials

Offered: 22W, 22S, 22X, 23W, 23S, 23X

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.

Prerequisites: PHYS 14 and CHEM 5

Dist: TLA

Instructors: Cullen, Fang, Frost, Levey, W. Li, Liu

ENGS 25 Introduction to Thermodynamics

Offered: 22W, 22S, 22X, 23W, 23S, 23X

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 60 students.

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

Dist: TAS

Instructors: Laser, Lynd, Samkoe

ENGS 26 Control Theory

Offered: 21F, 22S, 22F, 23S, 23F

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.

Prerequisites: ENGS 22

Dist: TAS

Instructors: Phan, Ray

ENGS 27 Discrete and Probabilistic Systems
Offered: 21F, 22X, 22F, 23X
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.
Prerequisites: MATH 8 and either ENGS 20 or COSC 1 and COSC 10. PHYS 13 or CHEM 5 recommended.
Dist: TAS
Instructors: Cybenko

ENGS 28 Embedded Systems
Offered: 22W, 23W
A vast number of everyday products, from home appliances to automobiles, are controlled by small embedded computers, invisible to the user. This course introduces, at an elementary level, the three basic components of all such embedded systems: sensors to measure the physical environment, actuators to produce the system behavior, and a microcontroller that processes the sensor data and controls the actuators. Topics: microcontroller architecture and programming, writing embedded software, analog- to-digital and digital-to-analog conversion, interfacing sensors and actuators, and data communication. There are daily in-class design exercises and weekly labs. Enrollment is limited.
Prerequisites: ENGS 20 or COSC 10; and PHYS 14 (may be taken concurrently)
Dist: TLA
Instructors: Bonfert-Taylor, Hansen

ENGS 30 Biological Physics (Identical to PHYS 30)
Offered: 22W, 23S
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.
Prerequisites: 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 instructor
Dist: TAS
Instructor: Samkoe

ENGS 31 Digital Electronics (Identical to COSC 56)
Offered: 22S, 22X, 23S, 23X
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 60 students.
Prerequisites: ENGS 20 or COSC 1 and COSC 10
Dist: TLA
Instructor: Hansen, Luke

ENGS 32 Electronics: Introduction to Linear and Digital Circuits (Identical to PHYS 48)
Offered: 21F, 22W, 22F, 23W, 23F
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.
Prerequisite: ENGS 22, or equivalent background in basic circuit theory
Dist: TLA
Instructors: Odame, Stauth

ENGS 33 Solid Mechanics
Offered: 21F, 22W, 22X, 22F, 23W, 23X, 23F
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 under-standing of the principles of solid mechanics.
Prerequisites: MATH 13 and PHYS 13
Dist: TLA
Instructors: Y. Li, Snyder

ENGS 34 Fluid Mechanics

Offered: 22S, 23S
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.
Prerequisites: ENGS 23 or equivalent
Dist: TLA
Instructor: Meyer

ENGS 35 Biotechnology and Biochemical Engineering
Offered: 21F, 22F, 23F
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.
Prerequisites: MATH 3, CHEM 5, BIOL 12 or BIOL 13 or permission of instructor
Dist: TLA
Instructor: Gerngross

ENGS 36 Chemical Engineering

Offered: 21F, 22F, 23F

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.

Prerequisites: ENGS 22, ENGS 25 and CHEM 5

Dist: TAS

Instructor: Lee

ENGS 37 Introduction to Environmental Engineering

Offered: 21F, 22F, 23F

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.

Prerequisites: MATH 3 and CHEM 5, or equivalent, or permission of instructor

Dist: TAS

Instructor: Cushman-Roisin

ENGS 41 Sustainability and Natural Resource Management

Offered: 22W, 23W

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 resources 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.

Prerequisites: MATH 23 or ENGS 22, and ENGS 37

Dist: TAS

Instructor: Cushman-Roisin

ENGS 43 Environmental Transport and Fate (Identical to EARS 66.01)

Offered: 22W, 23W

Introduction to the movement and transformation of contaminants released in soils, rivers, and the atmosphere. Fundamentals of advective-dispersive reactive transport, including approaches for assessing and parameterizing the complex heterogeneity and anisotropy of natural media. Analysis of mixing processes that lead to dispersion at larger spatial and temporal scales. Basic principles are illustrated by application to real world examples of groundwater, river, and atmospheric pollution.

Prerequisites: MATH 8 or equivalent and either ENGS 37 or EARS 16

Dist: TAS

ENGS 44 Sustainable Design
Offered: 22S, 23S
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 20 students.
Prerequisites: ENGS 21 and ENGS 22 or SART 65
Dist: TAS
Instructor: Kawiaka

ENGS 46 Advanced Hydrology (Identical to EARS 76)

Offered: 22F
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
Dist: TAS

ENGS 50 Software Design and Implementation (Identical to COSC 50)
Offered: 21F, 22F, 23F
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.
Prerequisites: COSC 10 or equivalent
Dist: TLA
Instructor: Kawiaka

ENGS 52 Introduction to Operations Research

Offered: 22W, 23W
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.
Prerequisites: MATH 8 and MATH 22 or equivalent
Dist: TAS
Instructor: Santos

ENGS 56 Introduction to Biomedical Engineering

Offered: 22S, 23S

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.

Prerequisites: ENGS 22

Dist: TAS

Instructors: Hoopes, Zhang

ENGS 57 Intermediate Biomedical Engineering

Offered: 22S, 23S

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.

Prerequisites: ENGS 23 and ENGS 56 or equivalent

Dist: TAS

Instructor: Halter

ENGS 58 Introduction to Protein Engineering

Offered: 22W, 23W

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

Dist: TAS

Instructors: Goods, Griswold

ENGS 59 Basic Biological Circuit Engineering

Offered: 22W, 23W

This course will provide a comprehensive introduction to the design, modeling, and experimental implementation of synthetic bio-molecular circuits in living cells at an undergraduate level. 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 laboratory tool. It will show them how to design, model, and fit actual experimental biological data such that engineering circuit theory and biological experiment agree.

Prerequisites: ENGS 22 or permission of instructor Experience in Molecular Biology is useful (e.g. ENGS 35, BIOL 45, & BIOL 46 or equivalent) but not necessary.

Dist: TLA

Instructors: Goods, Griswold

ENGS 60 Introduction to Solid-State Electronic Devices

Offered: 22W, 23W

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.

Prerequisites: ENGS 23
Dist: TLA
Instructor: Fossum

ENGS 61 Intermediate Electrical Circuits

Offered: 22S, 23S

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.

Prerequisites: ENGS 32
Dist: TLA
Instructor: Stauth

ENGS 62 Microprocessors in Engineered Systems

Offered: 22W, 23W

Microprocessors and microcomputers are central components in an ever-increasing number of consumer, industrial, and scientific products. This course extends the experimental design methodology developed in ENGS 50 to state-of-the-art System-on- Chip (SoC) architectures and explores the principles behind advanced embedded systems. SoC devices are highly-integrated components that combine high-performance multi-core processors, with Field Programmable Gate Array (FPGA), and a broad selection of industry standard peripheral interfaces — all within a single chip. Students are introduced to concepts of event-driven finite state machines, peripheral interfacing via the processor and the FPGA fabric, and advanced hardware-software co-design tools that speed the design process. The course is based on a sequence of laboratory projects that incorporate SoC programming practices and debugging strategies, interrupt handling, FPGA and bus interfaces, and attached peripheral devices.

Prerequisites: ENGS 50
Dist: TLA
Instructor: Taylor

ENGS 64 Engineering Electromagnetics
Offered: 21F, 22F, 23F

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
Dist: TAS
Instructor: Shubitidze

ENGS 65 Engineering Software Design
Offered: 22W, 23W

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.

Prerequisites: ENGS 20 or COSC 1 and COSC 10
Dist: TAS
Instructor: Santos

ENGS 66 Discrete Mathematics in Computer Science (Identical to COSC 30)
Offered: 21F, 22W, 22F, 23W, 23F

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.

Prerequisites: ENGS 20 or COSC 1 and COSC 10 or advanced placement
Dist: QDS

ENGS 67 Programming Parallel Systems (Identical to COSC 63)
Not offered 2021-2023

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
Dist: TLA

ENGS 68 Introduction to Communication Systems
Offered: 22W, 23W

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.

Prerequisites: ENGS 22, ENGS 27 and ENGS 92
Dist: TAS
Instructor: Testorf

ENGS 69 Smartphone Programming (Identical to COSC 65, COSC 165)
Offered: 21F, 22W, 22F, 23W, 23F

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

Dist: TAS

ENGS 71 Structural Analysis
Offered: 22S, 23S

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

Dist: TAS

Instructor: May

ENGS 72 Applied Mechanics: Dynamics
Offered: 22W, 23W

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.

Prerequisites: ENGS 22

Dist: TAS

Instructor: Kokko

ENGS 73 Materials Processing and Selection
Offered: 23S

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.

Prerequisites: ENGS 24 and ENGS 33 or equivalent

Dist: TLA

ENGS 75 Product Design

Offered: 22W, 23W

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. (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.)

Prerequisites: ENGS 21 or ENGS 89

Dist: TAS

Instructor: Robbie

ENGS 76 Machine Engineering

Offered: 21F, 22F, 23F

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.

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

Dist: TAS

Instructor: Halter

ENGS 84 Reading Course

Offered: 21F, 22W, 22S, 22X, 22F, 23W, 23S, 23X, 23F

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.

Prerequisites: 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: 21F, 22W, 22S, 22X, 22F, 23W, 23S, 23X, 23F

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.

Prerequisites: Permission of the Department Chair.

ENGS 85.09 Introduction to Computational Materials Science and Engineering

Offered: 22S, 23S

Computational modeling in materials science is a powerful tool that allows discovery of new materials and exploration of materials theory. This course introduces the use of computational modeling to understand and predict materials behavior, properties and processes. The course will introduce a series of common materials modeling approaches from molecular dynamics to Monte-Carlo simulations and Density Functional Theory. All methods will be illustrated using use cases from various fields of materials science (e.g., Li-ion batteries, structural alloys, etc.). The students will learn to apply these methods hands-on on specific problems writing code and using open-source codes. A strong emphasis will be on the critical assessment of the limits of the models
Prerequisites: ENGS 24, ENGS 20, and working knowledge of ordinary and partial differential equations. Students who do not meet prerequisite requirements and/or non-engineering majors may seek permission from the instructor.
Instructor: Hautier

ENGS 86 Independent Project

Offered: 21F, 22W, 22S, 22X, 22F, 23W, 23S, 23X, 23F

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. 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. (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

Offered: 21F, 22W, 22S, 22X, 22F, 23W, 23S, 23X, 23F

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. A report describing the details of the investigation must be filed with the department chair and approved at the completion of the course. (May not be used to satisfy any AB major or BE degree requirements)
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

Offered: 21F, 22W, 22S, 22X, 22F, 23W, 23S, 23X, 23F

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. May be counted as an elective in the Engineering Sciences major if ENGS 89 is taken as the culminating experience.)
Prerequisites: Permission of the Chair of the Honors program.

ENGS 89 Engineering Design Methodology and Project Initiation
Offered: 21F, 22F, 23F
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 proposals and progress reports 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.
Prerequisites: 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: Diamond, Steinhauer

ENGS 90 Engineering Design Methodology and Project Completion
Offered: 22W, 23W
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.
Prerequisites: ENGS 89
Instructors: Diamond, Steinhauer

ENGS 91 Numerical Methods in Computation (Identical to COSC 71)
Offered: 21F, 22F, 23F
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. (Can be used to satisfy graduate degree requirements.)
PrerequisiteS: ENGS 20 or COSC 1 and COSC 10; ENGS 22 or MATH 23, or equivalent
Dist: QDS
Instructor: Shepherd

ENGS 92 Fourier Transforms and Complex Variables (Identical to PHYS 70)
Offered: 21F, 22F, 23F
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 trans- forms, 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. (Can be used to satisfy graduate degree requirements.)
Prerequisite: MATH 46 or ENGS 22 and ENGS 23 or the equivalent
Dist: QDS
Instructor: Testorf

ENGS 93 Statistical Methods in Engineering
Offered: 21F, 22W, 22F, 23W, 23F
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. (Can be used to satisfy graduate degree requirements.)
Prerequisite: MATH 13 or equivalent
Dist: QDS
Instructors: Lasky, Vaze

Prerequisite Courses For Engineering Sciences Majors

The courses below reflect prerequisite courses for Engineering Sciences majors. Additional prerequisite courses not listed in this guide may also be required for modified majors. Please be advised that course descriptions, availability, and schedules are subject to change. For the most up-to-date course descriptions, offerings, time and location, and instructor information, please visit: dartmouth.edu/reg.

Chemistry

CHEM 5 General Chemistry
Offered: 21F, 22W, 22F, 23W, 23F
The first term of a two-course sequence to introduce 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. Students who are eligible to receive credit-on-entrance for CHEM 5-6 may not enroll in CHEM 5-6 or CHEM 10 for course credit without permission of the Department. Credit-on-entrance for CHEM 5-6 will be withdrawn for students who subsequently enroll in CHEM 5-6 or CHEM 10.
Prerequisites: MATH 3
Dist: SLA

CHEM 6 General Chemistry
Offered: 21F, 22S, 22F, 23S
The second term of a two-course sequence to introduce 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. Students who are eligible to receive credit-on-entrance for CHEM 5-6 may not enroll in CHEM 5-6 or CHEM 10 for course credit without permission of the Department. Credit-on-entrance for CHEM 5-6 will be withdrawn for students who subsequently enroll in CHEM 5-6 or CHEM 10.
Prerequisites: MATH 3 and CHEM 5. Supplemental course fee required.
Dist: SLA

CHEM 10 Honors First-Year General Chemistry

Offered: 21F, 22F, 23F

CHEM 10 is a general chemistry course for students with a strong background in chemistry and mathematics 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. Students with a score of 5 on the AP Chemistry examination and who also have credit on entrance (or the equivalent) for MATH 3 are automatically eligible to be considered for admission into CHEM 10. Students who have credit on entrance (or the equivalent) for MATH 3, but who do not have a score of 5 on the AP Chemistry examination, and who wish to be considered for CHEM 10 must take the Chemistry 10 Placement examination which is offered only during First-Year Orientation.

Prerequisites: Credit on entrance for CHEM 5, or satisfactory performance on the CHEM 10 Placement examination, and credit on entrance for MATH 3 or the equivalent. Supplementary course fee required. Students who complete CHEM 10 will also be granted credit on entrance for Chemistry 5, if they have not already been granted such credit.

Dist: SLA

Computer Science

COSC 1 Introduction to Programming and Computation

Offered: 21F, 22W, 22S, 22F, 23W, 23S

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: TLA

COSC 10 Problem Solving via Object-Oriented Programming

Offered: 21F, 22W, 22S, 22F, 23W, 23S

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.

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

Dist: TLA

Mathematics

MATH 3 Calculus

Offered: 21F, 22W, 22F, 23W, 23F

This course is an introduction to single variable calculus aimed at students who have seen some calculus before, either before matriculation or in MATH 1. MATH 3 begins by revisiting the core topics in MATH 1 (convergence, limits, and derivatives) in greater depth before moving to applications of differentiation such as related rates, finding extreme values, and optimization. The course then turns to integration theory, introducing the integral via Riemann sums, the fundamental theorem of calculus, and basic techniques of integration.

Dist: QDS

MATH 8 Calculus of Functions of One and Several Variables

Offered: 21F, 22W, 22S, 22F, 23W, 23S

This course is a sequel to MATH 3 and is appropriate for students who have successfully completed an AB calculus curriculum (or the equivalent) in secondary school. Roughly half of the course is devoted to topics in one-variable calculus, selected from techniques of integrations, areas, volumes, numerical integration, sequences and series including Taylor series, ordinary differential equations and techniques of their solution. The second half of the course 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 balance of the course is devoted to studying differential 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.

Prerequisites: MATH 3 or equivalent

Dist: QDS

MATH 11 Accelerated Multivariable Calculus

Offered: 21F, 22F, 23F

This briskly paced course can be viewed as equivalent to MATH 13 in terms of prerequisites, 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 multivariable calculus material present in MATH 8 together with the material from MATH 13. 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. ()

Prerequisites: MATH 8 or Math 9 or equivalent. Students who have successfully completed a BC calculus curriculum in secondary school may complete multivariable calculus either by taking the two term sequence MATH 9 and MATH 13 or by completing the single, faster-paced, MATH 11. Not open to students who have received credit for MATH 13.

Dist: QDS

MATH 13 Calculus of Vector-Valued Functions

Offered: 21F, 22W, 22S, 22F, 23W, 23S

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. First-year students who have received two terms of credit from the AP-BC exam generally should take MATH 11 instead. On the other hand, if the student has had substantial exposure to multivariable techniques, they are encouraged to consult with their First-year advisor during orientation week to determine if placement into MATH 13 is more appropriate.

Dist: QDS

MATH 22 Linear Algebra with Applications

Offered: 21F, 22S, 22F, 23S

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 MATH 63 or MATH 71 are strongly encouraged to take MATH 24.

Prerequisites: MATH 8

Dist: QDS

MATH 23 Differential Equations

Offered: 21F, 22W, 22S, 22F, 23W, 23S

This course is a survey of important types of differential equations, both linear and non-linear. 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.

Prerequisites: MATH 13

Dist: QDS

Physics

PHYS 13 Introductory Physics I

Offered: 21F, 22W, 22F, 23W, 23F

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

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

Dist: SLA

PHYS 14 Introductory Physics II

Offered: 22W, 22S, 23W, 23S

The fundamental laws of electricity and magnetism. Maxwell's equations. Waves. Electrical and magnetic properties of bulk matter. Circuit theory. Optics. One laboratory period per week.

Prerequisites: PHYS 13 and MATH 8, or permission of instructor

Dist: SLA


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Graduate Courses

Graduate Courses

engineering.dartmouth.edu/courses/graduate

Coursework for graduate degree programs is differentiated by field, discipline, or function. In our close-knit community, graduate students work closely with professors and peers, a significant feature in most of our graduate courses, in particular those that require in-depth study. Undergraduate engineering science majors may take graduate courses for which they are qualified. Please be advised that not all graduate courses, however, can be used to satisfy AB and/or Engineering Sciences major requirements.

Guide to Graduate Course Listings

Course Prefix

The prefix before the course number—ENGS, ENGG, or ENGM—provides context for the degree requirements that specific courses satisfy and the type of credit granted.

PREFIX	DESCRIPTION
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 the requirements for the MEM degree. They do not satisfy degree requirements for the Engineering Sciences major.

Course Numbers

Graduate engineering courses are numbered 100 to 200, and most have prerequisites or other minimum requirements. Courses number 300 and above are considered advanced graduate courses. Undergraduate engineering science majors may take graduate courses for which they are qualified. Not all graduate courses, however, can be used to satisfy the AB and/or Engineering Sciences major requirements.

NUMBER	DESCRIPTION
90-99	Advanced undergraduate-level courses with significant design, research, or project work.
100-199	Graduate-level courses, with engineering prerequisites, numbered below 100.
200-299	Graduate-level courses, with engineering prerequisites, numbered below 200.
300-399	Advanced graduate-level courses, distinguished by the standard of accomplishments required. 300-level courses comprise an in-depth study of an area of engineering or engineering sciences up to the point where the student is able effectively to read and evaluate current literature in the field and to the point where the student should be ready to undertake original work in the field.

Terms Offered

Information about the terms when courses will be offered reflects the plan for the next two academic years. Not all courses listed are offered each year, and course availability is subject to change. For the most current information, consult the course descriptions and schedules on the website: engineering.dartmouth.edu/courses/graduate.

2021-2022		2022-2023		2023-2024	
21F:	Fall 2021	**22F:**	Fall 2021	**23F:**	Fall 2023
22W:	Winter 2022	**23W:**	Winter 2022	**24W:**	Winter 2024 (if available)
22S:	Spring 2022	**23S:**	Spring 2022	**24S:**	Spring 2024 (if available)
22X:	Summer 2022	**23X:**	Summer 2022	**24X:**	Summer 2024 (if available)

Class Schedule and Time Periods

Course times are *not listed* in the printed guide as they are subject to change. Graduate courses at Thayer follow a similar timetable to Dartmouth's undergraduate courses. The number or number-letter combination represents the day(s) of the week and the time period in which classes are offered. The X-period time is set aside for instructors to use as needed. For some courses, the X-period is an additional class session.

For the most up-to-date course descriptions, offerings, time and location, and instructor information, please visit Dartmouth Timetable of Class Meetings (oracle-www.dartmouth.edu/dart/groucho/timetable.main) or Thayer's undergraduate course listings online (engineering.dartmouth.edu/courses/graduate).

CLASS*	DAY(S)	TIME	X-PERIOD	DAY	TIME
8S	MTuThF	7:45–8:35 a.m.	**8SX**	W	7:45–8:35 a.m.
8L	MWF	7:30–8:35 a.m.	**8LX**	Th	7:45–8:35 a.m.
9S	MTuThF	9:05–9:55 a.m.	**9SX**	W	9:05–9:55 a.m.
9L	MWF	8:50–9:55 a.m.	**9LX**	Th	9:05–9:55 a.m.
10	MWF	10:10–11:15 a.m.	**10X**	Th	12:15–1:05 p.m.
10A	TuTh	10:10 a.m.–12:00 p.m.	**10AX**	F	3:30–4:20 p.m.
11	MWF	11:30–12:35 p.m.	**11X**	Tu	12:15–1:05 p.m.
12	MWF	12:50–1:55 p.m.	**12X**	Tu	1:20–2:10 p.m..
2	MWF	2:10–3:15 p.m.	**2X**	Th	1:20–2:10 p.m.
2A	TuTh	2:25–4:15 p.m.	**2AX**	F	4:35–5:25 p.m.
3A	MW	3:30–5:20 p.m.	**3AX**	M	5:30–6:20 p.m.
3B	TuTh	4:30–6:20 p.m.	**3BX**	W	5:30–6:20 p.m.
6A	MW	6:30–8:20 p.m.	**6AX**	Tu	6:30–7:20 p.m.
6B	W	6:30–9:30 p.m.	**6BX**	Tu	7:30–8:20 p.m.

* This reflects the class schedule, as of Fall 2021. For the most current information, consult Dartmouth's Weekly Class Diagram on Dartmouth's Office of the Registrar's website.

Course Cancellation Policy

Please be advised that any listed course may be canceled if the enrollment is fewer than five students.

Graduate Courses by Topic

Topic	Courses
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 ENGS 103 Operations Research ENGS 104 Optimization Methods for Engineering Applications ENGS 105 Computational Methods for Partial Differential Equations I ENGS 106 Numerical Linear Algebra ENGG 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
Bioengineering	ENGS 159 Molecular Sensors & Nanodevices in Biomedical Engineering 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 260 Advances in Biotechnology ENGG 261 Biofuels and Bioenergy ENGS 262 Advanced Biological Circuit Engineering ENGG 269 Advances in Biomedical Engineering ENGG 365 Advanced Biomaterials ENGG 367 Heat Transfer in Hyperthermia
Computers and Communications	ENGS 108 Applied Machine Learning ENGS 110 Signal Processing ENGS 111 Digital Image Processing ENGS 112 Modern Information Technologies ENGG 113 Image Visualization and Analysis ENGS 114 Networked Multi-Agent Systems ENGS 115 Parallel Computing ENGS 116 Computer Engineering: Computer Architecture ENGG 210 Spectral Analysis ENGG 212 Communications Theory ENGG 310 Advanced Topics in Signals and Systems ENGG 312 Topics in Statistical Communication Theory ENGG 317 Topics in Digital Computer Design

Graduate Courses by Topic (continued on next page)

Graduate Courses by Topic (continued from previous page)

Electromagnetics, Optics, Electronics, and Circuits	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 ENGS 220 Electromagnetic Wave Theory ENGG 324 Microstrip Lines and Circuits
Engineering Management	ENGG 176 Design for Manufacturing ENGG 177 Decision-Making under Risk and Uncertainty ENGM 178 Technology Assessment ENGM 179.1 Strategy ENGM 179.2 Organizational Behavior ENGM 180 Accounting and 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 187 Technology Innovation and Entrepreneurship ENGM 188 Law for Technology and Entrepreneurship ENGM 189.1 Medical Device Commercialization (.5 credit) ENGM 189.2 Medical Device Development (.5 credit) ENGM 190 Platform Design, Management, and Strategy ENGM 191 Product Design and Development ENGM 387 MEM Professional Skills ENGG 390 Master of Engineering Management Project
Energy and Environmental Engineering	ENGS 171 Industrial Ecology ENGS 172 Climate Change and Engineering ENGG 173 Energy Utilization ENGS 174 Energy Conversion ENGS 175 Energy Systems
Fluids, Transport, and Chemical Processes	ENGS 150 Intermediate Fluid Mechanics ENGS 151 Environmental Fluid Mechanics ENGS 152 Magnetohydrodynamics ENGS 153 Computational Plasma Dynamics ENGS 155 Intermediate Thermodynamics ENGS 156 Heat, Mass, and Momentum Transfer ENGS 157 Chemical Process Design ENGS 158 Chemical Kinetics and Reactors ENGS 250 Turbulence in Fluids

Graduate Courses by Topic (continued on next page)

Graduate Courses by Topic (continued from previous page)

Materials Science	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 ENGS 137 Molecular and Materials Design using Density Functional Theory ENGG 138 Corrosion and Degradation of Materials ENGG 139.1 Polar Science and Engineering: Solidification, Sea Ice, Strength and Fracture of Ice ENGG 139.2 Polar Science and Engineering: Physics and Chemistry of Ice, Polar Glaciology, Remote Sensing ENGG 230 Fatigue and Fracture ENGG 332 Topics in Plastic Flow and Fracture of Solids ENGG 339 Advanced Electron Microscopy
Mechanics, Dynamics and Control	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 ENGG 240 Kinematics and Dynamics of Machinery
MS & PhD Research	ENGG 296 Graduate Research 1 ENGG 297 Graduate Research 2 ENGG 298 Graduate Research 3 ENGG 700 Responsible & Ethical Conduct of Research
Independent Study, Seminars, and New Courses	ENGG 195 Seminar on Science - Technology and Society ENGG 197 Ph.D. Professional Workshops ENGG 198 Research-In-Progress Workshop ENGG 199 Special Topics in Engineering Sciences ENGG 199.2 Model Based Systems Engineering ENGG 199.3 High-Frequency Power Magnetics Design ENGG 199.4 Techno-economic Analysis in a Developing Country Context ENGG 299 Advanced Special Topics in Engineering Sciences
PhD Innovation Program	ENGG 300 Enterprise Experience Project ENGG 321 Advanced Innovation and Entrepreneurship ENGG 325 Introduction to Surgical Innovation

Graduate Course Descriptions

Please be advised that course descriptions, availability, and schedules are subject to change. For the most up-to-date course descriptions, offerings, time and location, and instructor information, please visit engineering.dartmouth.edu/courses/graduate.

ENGS 91 Numerical Methods in Computation (Identical to COSC 71)
Offered: 21F, 22F, 23F
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. ENGS 91 may not be used by mathematics or computer science majors in partial satisfaction of the distributive requirement.
Prerequisites: ENGS 20 or COSC 1 and COSC 10; ENGS 22 or MATH 23, or equivalent
Dist: QDS
Instructor: Shepherd

ENGS 92 Fourier Transforms and Complex Variables (Identical to PHYS 70)
Offered: 21F, 22F, 23F
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.
Prerequisites: MATH 46 or ENGS 22 and ENGS 23 or equivalents
Dist: QDS
Instructor: Testorf

ENGS 93 Statistical Methods in Engineering
Offered: 21F, 22W, 22F, 23W, 23F
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.
Prerequisites: MATH 13 or equivalent
Dist: QDS
Instructors: Lasky, Vaze

ENGS 100 Methods in Applied Mathematics I
Offered: 21F, 22F, 23F
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 equivalent
Instructors: Meyer

ENGS 103 Operations Research

Offered: 22S, 23S

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.

Prerequisites: ENGS 93 or equivalent

Instructor: Vaze

ENGS 104 Optimization Methods for Engineering Applications

Offered: 21F (Not offered 2022-2023)

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.

Prerequisites: MATH 22 and ENGS 27 or equivalent, or permission of instructor

ENGS 105 Computational Methods for Partial Differential Equations

Offered: 22W

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 2021-2023

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).

Prerequisites: 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 2021-2023

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: 21F, 22F, 23F

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 74/274.

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

Instructor: Cybenko

ENGS 110 Signal Processing

Offered: 22S, 23S

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 which require the use of the computer.

Prerequisites: ENGS 32 and ENGS 92 or equivalents

Instructor: Hansen

ENGS 111 Digital Image Processing

Offered: 22S, 23S

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: 23S

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.

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

Instructor: Santos

ENGG 113 Image Visualization and Analysis
Offered: 22S
The goal of this course is to introduce graduate level and senior undergraduate students who are working in imaging research to image processing and visualization in 3D using advanced libraries and fully functional software development framework. The most widely used open source software tools for medical image analysis and visualization will be used as the platform: The Insight Registration Segmentation Toolkit (ITK), the Visualization Toolkit (VTK), OpenCV, Qt, and CMake. ITK is an open-source, widely adopted, cross-platform system that provides developers with an extensive suite of software tools for image analysis, including fundamental algorithms for image segmentation and registration. VTK is an open-source, widely adopted, software system for 3D computer graphics, modeling, image processing, volume rendering, scientific visualization, and information visualization. The student will gain understanding of the working of all subroutines and practical application implementing these routines into customized workflow. The course will also introduce the use of OpenCV for applying computer vision and machine learning algorithms to biomedical images and data. Moreover, a full software development environment will be employed to create release-quality applications. This will include the use of source version control to track code changes and bugs, Qt for user interface development, CMake for development environment control, and Visual Studio C++ for the coding environment (Python is also permitted for students with substantial experience working with the language). This state of the art forms the basis for most medical visualization software used today, and students will learn the use of these tools and complete required exercises and projects, with an emphasis on real-world clinical applications.
Prerequisites: ENGS 65 or permission of instructor
Instructor: Jermyn

ENGS 114 Networked Multi-Agent Systems
Not offered 2021-2023
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.
Prerequisites: ENGS 26, MATH 23, or equivalents plus familiarity with MATLAB

ENGS 115 Parallel Computing
Not offered 2021-2023
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 as seismic processing, fluid mechanics, and molecular dynamics.
Prerequisites: ENGS 91 (or COSC 71 or equivalent)

ENGS 116 Computer Engineering: Computer Architecture (Identical to COSC 251)
Not offered 2021-2023
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 hard- ware/software trade offs. 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.
Prerequisites: ENGS 31 and COSC 51; COSC 57, COSC 58, or equivalent recommended

ENGS 120 Electromagnetic Waves: Analytical and Modeling Approaches
Offered: 22W, 23W

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.

Prerequisites: ENGS 64 or equivalent

Instructor: Luke

ENGG 122 Advanced Topics in Semiconductor Devices
Offered: 21F, 22F, 23F

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.

Prerequisites: ENGS 60 or equivalent

Instructor: Scheideler

ENGS 123 Optics (Identical to PHYS 123)
Offered: 22W, 23W

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.

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

Instructor: Luke

ENGS 124 Optical Devices and Systems (Identical to PHYS 124)
Offered: 22S, 23S

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.

Prerequisites: ENGS 23

Instructor: Liu

ENGS 125 Power Electronics and Electromechanical Energy Conversion
Offered: 22W, 23W

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.

Prerequisites: ENGS 23 and ENGS 32

Instructor: Stauth

ENGS 126 Analog Integrated Circuit Design

Offered: 21F, 22F, 23F

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.

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

Instructor: Odame

ENGS 128 Advanced Digital System Design

Offered: 23S

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.

Prerequisites: ENGS 31 and ENGS 62 or COSC 51

Instructor: Hansen

ENGS 129 Biomedical Circuits and Systems

Offered: 22S, 23S

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.

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

Instructor: Odame

ENGS 130 Mechanical Behavior of Materials

Offered: 21F, 22F, 23F

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.

Prerequisites: ENGS 24 and ENGS 33, or equivalent

Instructor: Schulson

ENGS 131 Science of Solid State Materials

Offered: 21F, 22F, 23F

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.

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

Instructor: Liu

ENGS 132 Thermodynamics and Kinetics in Condensed Phases

Offered: 22W, 23W

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 diffusionless 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.

Prerequisites: ENGS 24 and ENGS 25, or equivalent

Instructor: Schulson

ENGS 133 Methods of Materials Characterization (Identical to PHYS 128 and CHEM 137)

Offered: 22S, 23S

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 of instructor

Instructor: Baker

ENGS 134 Nanotechnology

Offered: 22W, 23W

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: Baker

ENGS 135 Thin Films and Microfabrication Technology

Offered: 22W

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

ENGS 137 Molecular and Materials Design using Density Functional Theory

Offered: 21F

Density Functional Theory (DFT) has become a very powerful tool to compute and predict the properties of molecules and materials. This class will focus on how DFT can be used to compute a large range of materials and molecules properties. The class will expose the fundamentals of DFT but also the practical aspects involved in running computations. A comprehensive number of properties will be studied: structural, mechanical, thermodynamical, optical, electrical and magnetic. The student will learn how to use a DFT code through computational problem sets. The class will as well focus on case studies from the scientific literature presented by students and discussed in class. A strong emphasis will be on the critical assessment of the results obtained by DFT and on the use of the technique to perform prediction and design.

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

Instructor: Hautier

ENGG 138 Corrosion and Degradation of Materials

Offered: 22S, 23S

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

Prerequisites: ENGS 24 and CHEM 5

ENGG 139.1 Polar Science & Engineering: Solidification, Sea Ice, Strength & Fracture of Ice

Offered: 22S

This course focuses on three topics relevant to science and engineering within the polar regions of Earth: solidification of fluids, the nature of sea ice and the strength and fracture of ice .Each topic is treated as a separate module, 8-10 lectures in length.

Prerequisites: ENGS 23 or permission of instructor

Instructor: Schulson

ENGG 139.2 Polar Science & Engineering: Physics & Chemistry of Ice, Polar Glaciology, Remote Sensing

Offered: 23S

This course focuses on three topics relevant to science and engineering within the polar regions of Earth: physics and chemistry of ice, glacial hydrology and remote sensing of polar landscapes., 8-10 lectures in length.

Prerequisites: ENGS 24, general chemistry (full year), or permission of instructor

Instructor: Schulson

ENGS 142 Intermediate Solid Mechanics
Offered: 21F, 22F, 23F

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.

Prerequisites: ENGS 71 or ENGS 76 or equivalent

Instructor: Y. Li

ENGS 145 Modern Control Theory
Offered: 22S, 23S

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, and 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.

Prerequisites: ENGS 26

Instructor: Phan

ENGS 146 Computer-Aided Mechanical Engineering Design
Offered: 22S, 23S

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: 23S

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.

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

Instructor: Ray

ENGG 148 Structural Mechanics

Offered: 22F

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

Prerequisite: ENGS 33

Instructor: Phan

ENGG 149 Introduction to Systems Identification

Offered: 22W

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: 22W, 23W

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 instructor

Instructor: Meyer

ENGS 151 Environmental Fluid Mechanics

Offered: 22S, 23S

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, e.g., sea breeze in the context of the lower atmospheric boundary layer.

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

Instructor: Cushman-Roisin

ENGS 152 Magnetohydrodynamics (Identical to PHYS 115)

Offered: 22S

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.

Prerequisites: PHYS 68 or equivalent, or permission of instructor

ENGS 153 Computational Plasma Dynamics (Identical to PHYS 118)

Offered: 22W

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

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

ENGS 155 Intermediate Thermodynamics

Offered: 22S, 23S

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.

Prerequisites: ENGS 25

Instructor: Frost

ENGS 156 Heat, Mass, and Momentum Transfer

Offered: 22S, 23S

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.

Prerequisites: ENGS 25, ENGS 34

Instructor: Lasky

ENGS 157 Chemical Process Design

Offered: 22W, 23W

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.

Prerequisites: ENGS 36

Instructor: Laser

ENGS 158 Chemical Kinetics and Reactors

Offered: 22S, 23S

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.

Prerequisites: ENGS 36

Instructor: Laser

ENGS 159 Molecular Sensors and Nanodevices in Biomedical Engineering

Offered: 22S, 23S

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; microarray analysis of biomolecules; semiconductor and metal nanosensors; microfluidic systems; and microelectromechanical 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.

Prerequisites: ENGS 22, CHEM 6, or equivalent

Instructor: Zhang

ENGS 160 Biotechnology and Biochemical Engineering

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.

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

ENGS 161 Metabolic Engineering

Offered: 23S

Metabolic engineering combines aspects of chemical engineering, systems biology and synthetic biology. This course focuses on developing a quantitative understanding of metabolic processes within the cell. Although metabolism is a complex process, it is determined by a small number of physical constraints, including enzyme activity, mass balance and thermodynamics. In this course you will learn to perform a mass balance, construct and analyze a stoichiometric network, simulate a series of kinetic reactions, and analyze isotope tracer experiments. Key genetic techniques, including CRISPR, will be presented. Computational analysis will be performed using COBRA and Equilibrator via Python and associated tools in the Python Data Science stack. These tools will be applied first to several canonical examples from the metabolic engineering literature and then to a project of your choosing.

Prerequisites: ENGS 35/160 and a non-introductory course in biochemistry or molecular biology, or permission of instructor

Instructor: Olson

ENGS 162 Basic Biological Circuit Engineering

Offered: 22W, 23W

This course will provide a comprehensive introduction to the design, modeling, and experimental implementation of synthetic bio-molecular circuits in living cells, which have wide applications in biotechnology and medicine. Simple but sophisticated synthetic biological circuits will be implemented and tested in microbial cells in the laboratory. Computer aided design, modeling, and simulation will use 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.

Prerequisites: 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

Offered: 22W, 23W

This course will build on molecular engineering fundamentals introduced in ENGS 58 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. (Not open to AB and BE students. Students in these degree programs are encouraged to enroll in ENGS 58.)

Prerequisites: ENGS 160 OR BIOCHEM 101. Equivalent courses accepted with instructor's permission.

Instructor: Lee

ENGS 165 Biomaterials

Offered: 22S, 23S

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.

Prerequisites: ENGS 24, or equivalent

Instructor: Van Citters

ENGG 166 Quantitative Human Physiology

Offered: 22S

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

Prerequisites: ENGS 22 or equivalent; BIOL 12 or BIOL 14 or ENGS 30; ENGS 23 or MATH 23 or PEMM 101

Instructor: Pogue

ENGS 167 Medical Imaging

Offered: 22W, 23W

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.

Prerequisites: ENGS 92 (may be taken concurrently)

Instructor: Pogue

ENGG 168 Biomedical Radiation Transport

Offered: 21F

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.

Prerequisites: ENGS 23 or equivalent

Instructor: Pogue

ENGS 169 Intermediate Biomedical Engineering

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.

Prerequisites: ENGS 23 and ENGS 56 or equivalent

Instructor: Pogue

ENGS 170 Neuroengineering

Not offered 2021-2023

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.

Prerequisites: ENGS 22 and ENGS 56

ENGS 171 Industrial Ecology

Offered: 22W, 23W

A product's environmental impacts result from design, production, and operational choices. Industrial ecology identifies economic ways to improve these environmental impacts, chiefly by designing for circular material flows, improving energy effectiveness and material choice, changing user behavior, systems thinking, and otherwise promoting sustainability. The objective of this course is to do all of the above for a product to conceptually invent or innovate a market- viable alternative. To do this, a broad spectrum of industrial activities is reviewed, including products and services. This course examines to what extent environmental and social concerns have already affected specific industries, and where additional progress can be made. Student activities include a critical review of current literature, participation in class discussion, and a term project in design for the environment.
Prerequisites: ENGS 21 and ENGS 37 or instructor permission for MBA students. Students should have a basic understanding of how to progress from initial concept to prototype, and should have a basic understanding of environmental impacts such as pollution and climate change.
Instructor: Cushman-Roisin

ENGS 172 Climate Change and Engineering

Offered: 22S, 23S

Earth's climate is the 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: 22W, 23W

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

ENGS 174 Energy Conversion
Offered: 21F, 22F, 23F

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: 22S, 23S

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 instructor

Instructor: Farid

ENGG 176 Design for Manufacturing
Not offered 2021-2023

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.

Prerequisites: ENGS 73 or permission of instructor

ENGG 177 Decision-Making under Risk and Uncertainty
Not offered 2021-2023

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

Offered: 21F, 22F, 23F
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. (Cannot be used to satisfy any AB degree requirements)
No prerequisites
Instructor: Bish, Gortner

ENGS 179.1 Organizational Behavior

Offered: 21F, 22F, 23F
Strategy entails shaping and managing factors that are critical to the long-term success of an organization. Decision makers must formulate and implement strategy for the organization as a whole, and guide the organization in navigating strategic challenges as markets and technologies change. This course covers key frameworks and principles for formulating and implementing strategy in single-business and multi-business firms, with respect to the external context in which a firm competes and its internal operations. Applying this material to case studies and other company examples will help you to develop your skills in strategic analysis.

ENGS 179.2 Strategy

Offered: 22S, 23S
Organizations are complex social systems that bring together tasks, structures, people and culture. Their success depends on people interacting within this system to achieve common goals. This course will provide you with conceptual frameworks for increasing individual, team, and organizational performance. More specific learning goals include: a) to increase your knowledge about individual, interpersonal and group behavior in complex organizations; b) to increase your awareness of your own and others' assumptions, motivations, attitudes, values, emotions and behavior in human interaction; c) to increase your skill in diagnosing the structural and behavioral antecedents of destructive behavior in organizations, and prescribing effective action to remedy those problems; and d) to manage this complex system in service of achieving strategic goals. We will address these goals by learning about the underlying psychological and sociological foundations of human behavior and will engage in case study discussions and interactive exercises to help you build effective leadership skills.

ENGM 180 Accounting and Finance

Offered: 21F, 22F, 23F
This course provides an integrated exploration of financial accounting and finance. Financial accounting refers to the system a firm uses to both record its transactions and report its results to investors and other users of financial statements. Finance refers to the financial aspects of managerial decisions and the capital markets in which firms raise funds for investment to provide practical tools for financial decision making and valuation. (Cannot be used to satisfy any AB degree requirements)
No prerequisites
Instructors: Sansing, Severino

ENGM 181 Marketing

Offered: 21F, 22F, 23F

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

Prerequisites: Permission of instructor

ENGM 182 Data Analytics

Offered: 22S, 23S

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.

Prerequisites: ENGS 93 or equivalent or permission of instructor

Instructor: Parker

ENGM 183 Operations Management

Offered: 22W, 23W

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

Prerequisites: ENGS 93

ENGM 184 Introduction to Optimization Methods

Offered: 22W, 23W

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

No prerequisites

Instructor: Bish

ENGM 185 Topics in Manufacturing Design and Processes

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

Prerequisites: ENGS 93

ENGM 186 Technology Project Management

Offered: 22S, 23S

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

Prerequisites: ENGM 184 or equivalent

Instructor: Bish

ENGM 187 Technology Innovation and Entrepreneurship

Offered: 23W

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

No prerequisites

Instructor: Fossum

ENGM 188 Law for Technology and Entrepreneurship

Offered: 21F, 22F, 23F

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

No prerequisites

Instructor: Goodenough

ENGM 189 Topics in Engineering Management

This course consists of two mini-courses (0.5 credits each):

ENGM 189.01 Medical Device Commercialization (0.5 credit)

Offered: 22F

This course is designed to expose students to the specialized business frameworks and essential tools for successful translation of biomedical technologies from the lab (concept) to the market (clinic) that are needed by medical device innovators and managers. The curriculum is intended to provide an overview of the process used to assess the commercial viability and potential business opportunity for innovative medical devices. Course content is based on the Concept to Clinic: Commercializing Innovation (C3i) Program offered by the NIH. Teams of 2-3 students will work to develop a commercialization plan for an innovative medical device of their choosing or one provided by the course instructors. Weekly lectures on topics ranging from business validation to regulatory strategies to reimbursement approaches will be followed by team presentations that define how each team proposes to navigate these aspects of medical device commercialization. Two classes per week, 5 weeks total. (Cannot be used to satisfy any AB degree requirements)

Prerequisites: Graduate standing in engineering or business administration.

Instructor: Halter

ENGM 189.02 Medical Device Development

Offered: 22F

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 preclinical 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.

Prerequisites: Graduate standing in engineering or business administration

Instructor: Paulsen

ENGM 190 Platform Design, Management, and Strategy

Offered: 21F, 22F, 23F

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

No prerequisites

Instructor: Parker

ENGM 191 Product Design and Development

Offered: 21F, 22F, 23F

This class teaches modern tools and methods for product design and development. The cornerstone is a project in which student teams conceive, design, and prototype a physical product. The class is primarily intended for Thayer MEM, MEng, Thayer PhD Innovation, Tuck MBA students, and Dartmouth medical students. (Cannot be used to satisfy any AB degree requirements)

Prerequisites: ENGM 183 or permission of instructor

Instructor: Murnane

ENGG 192 Independent or Group Study in Engineering Sciences

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

ENGG 194 PhD Oral Qualifier

Offered: All terms (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. (Cannot be used to satisfy any AB, BE, MEM, MEng, or MS degree requirements.)

Prerequisites: PhD student standing

ENGG 195 Seminar on Science, Technology, and Society

Offered: 21F

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

Prerequisites: PhD student standing

Instructor: Baker

ENGG 197 PhD Professional Workshops

Offered: 22W, 23W

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

Prerequisites: PhD student standing

ENGG 198 Research-In-Progress Workshop

Offered: 22W, 23W

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

Prerequisites: PhD student standing

Instructor: Baker

ENGS 199 Special Topics in Engineering Sciences

(Cannot be used to satisfy any AB degree requirements)

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.

ENGG 199.1 Advanced Electrochemical Energy Materials

Offered: 21F

Electrochemical energy materials and devices are playing a vital role in our technology driven society, and are in massive and rapidly growing demand for applications ranging from portable electronics to electric cars, and from grid-level energy storage to defense purposes. This course will give an introduction to the materials developments and characterizations in diverse electrochemical devices, with a focus on various electrode materials and technologies. Topics include, for example, basic principles of electrochemistry; introduction of a series of electrochemical energy storage devices; materials in emerging new battery technologies; photoelectrochemistry and photovoltaic devices. This course focuses on understanding materials science and challenges in modern electrochemical devices. For example, how to engineer the structures and properties of materials to maximize their electrochemical performances? How to characterize structures and compositions of electrochemical materials? The course also includes guest lectures to introduce a variety of energy materials for broad applications, such as solar and electrochemical sensing, toxicity and sustainability of energy materials.

Prerequisites: ENGS 24 or equivalent. (It is assumed that students do not have background in electrochemistry.)

Instructor: W. Li

ENGG 199.2 Model Based Systems Engineering

Offered: 21F

This course is designed to introduce students to the world of model-based systems engineering. Systems Engineering is an interdisciplinary field of engineering and engineering management that enables the realization of successful complex systems over their life-cycles. Systems Engineering integrates multiple disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation to obsolescence. Systems Engineering considers the technical, social, and business needs of all stakeholders with the goal of realizing a successful system. At its core, systems engineering utilizes systems thinking principles to organize this body of knowledge. This course will prepare students to engineer, analyze, and simulate complex systems. Such systems are characterized by a high level of heterogeneity and a large number of components. They will appreciate the physical, informatic, social and economic aspects of such systems. They will use systems thinking concepts and abstractions to manage complexity. They will learn to use model-based systems engineering techniques to model a system's form, function, and concept. They will analyze the structure of these systems using graph-theoretic approaches. Finally, they will learn to simulate social, technical, and economic systems with continuous-time and discrete-event dynamics. The systems engineering skills developed over the course are applicable to a broad range of disciplinary applications.

Prerequisites: ENGS 199, like other introductory graduate-level systems engineering courses at other universities, is meant to be taken after the student has well established their undergraduate engineering program.

Instructor: Farid

ENGG 199.3 High-Frequency Power Magnetics Design

One of the fundamental advantages of power electronics is the ability to use high frequencies which enable reductions in physical size, weight and cost of passive components such as magnetics with losses also reduced. However high-frequency effects in both magnetic cores and in windings rapidly increase power losses at higher frequencies limiting performance and inhibiting the use of increased frequency to yield further improvements. After a review of magnetics modeling and design fundamentals, the class will examine best-practice techniques for high-frequency magnetics modeling and design. Selected recent and current research in modeling, design, and fabrication will be examined in detail, including self-resonant passive components. Finally, applications to wireless power transfer will be studied.

Instructor: Sullivan

ENGG 199.4 Techno-economic Analysis in a Developing Country Context

This course will address the application of techno-economic analysis (TEA) to evaluate the profitability and broader social and environmental impact of potential business ventures involving technologies located in developing countries. Elements of techno-economic analysis will be discussed, including process design and simulation; profitability analysis; and life-cycle assessment. Aspects unique to developing countries – such as poor infrastructure, financing limitations, and unfavorable government policies – will also be considered. Ongoing review and discussion of illustrative TEA examples, including case studies of actual ventures, will reinforce key concepts. The course will also feature a series of expert guest speakers from industry, academia, and non-profit organizations.

Prerequisites: ENGS 22 and ENGS 25

Instructor: Laser

ENGG 199.5 Introduction to Computational Materials Science and Engineering

Computational modeling in materials science is a powerful tool that allows discovery of new materials and exploration of materials theory. This course introduces the use of computational modeling to understand and predict materials behavior, properties and processes. The course will introduce a series of common materials modeling approaches from molecular dynamics to Monte-Carlo simulations and Density Functional Theory. All methods will be illustrated using use cases from various fields of materials science (e.g., Li-ion batteries, structural alloys, ...). The students will learn to apply these methods hands-on on specific problems writing code and using open-source codes. A strong emphasis will be on the critical assessment of the limits of the models.

Prerequisites: ENGS 24, ENGS 20, and working knowledge of ordinary PDE's. Students not meeting the prerequisites and non-engineering majors may seek permission.

Instructor: Hautier

ENGS 200 Methods in Applied Mathematics II (Identical to PHYS 110)

Not offered 2021-2023

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.

Prerequisites: ENGS 100, or equivalent

ENGS 202 Nonlinear Systems

Not offered 2021-2023

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.

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

ENGS 205 Computational Methods for Partial Differential Equations II
Offered: 22S
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 Helmhotz-type problems associated with EM and physical oceanography.
Prerequisites: ENGS 105
Instructor: Paulsen

ENGG 210 Spectral Analysis
Not offered 2021-2023
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. (Can be used by undergraduates for AB course count only.)
Prerequisites: ENGS 110

ENGG 212 Communications Theory
Not offered 2021-2023
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. (Can be used by undergraduates for AB course count only.)
Prerequisites: ENGS 110

ENGS 220 Electromagnetic Wave Theory
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. (Can be used by undergraduates for AB course count only.)
Prerequisites: ENGS 100 and ENGS 120 or permission of instructor
Instructor: Shubitidze

ENGG 230 Fatigue and Fracture
Offered: 22S, 23S
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. (Can be used by undergraduates for AB course count only.)
Prerequisites: ENGS 130 or permission of instructor
Instructor: Y. Li

ENGG 240 Kinematics and Dynamics of Machinery

Not offered 2021-2023

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

Prerequisites: ENGS 72

ENGS 250 Turbulence in Fluids

Not offered 2021-2023

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.

Prerequisites: ENGS 150 or equivalent

ENGG 260 Advances in Biotechnology

Offered: 21F, 22W, 22S, 22F, 23W, 23S, 23F

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

Offered: 21F, 22F, 23F

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 bio commodity products. (Can be used by undergraduates for AB course count only.)

Prerequisites: ENGS 157 and ENGS 161 and permission of instructor

Instructor: Lynd

ENGS 262 Advanced Biological Circuit Engineering

Offered: 22S, 23S

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.

Prerequisites: 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 269 Advances in Biomedical Engineering

Offered: 22W, 22S

The field of biomedical engineering (BME) is expansive and growing, with expertise areas in each of 1) imaging and medical physics; 2) biomaterials & biomechanics, 3) devices and interventions; and 4) molecular and cellular engineering, and this journal club class will focus on one of these areas or a combination of them as designed each term. Our fundamental knowledge of systems and methods that form this evolution are being updated and revised on a daily basis, through academic research. The engineering and applied science aspects of these areas are published in scholarly journals and conference proceedings, and the fundamental discoveries and advances need to be understood. To be competitive within their professions, biomedical 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. The topic of each term will vary with the students enrolled, and several BME offerings with slightly different topic focus may occur. PhD students are expected to take this course each term of their first year, ideally, and receive a total of one course credit.

Prerequisites: PhD standing

Instructor: Pogue

ENGS 295 Supervised Undergraduate Teaching

Offered: All Terms (Arrange)

Students enrolled in this course will work closely with a faculty member to provide assistance in teaching an undergraduate engineering course. Students are expected to devote twenty hours per week to one or more of the following activities: developing assignments, preparing and delivering material (e.g., a lecture, in-class activity, discussion) for one or more class hours, organizing and delivering tutorials or problem sessions, laboratory instruction, evaluating student responses, and grading. Performance will be monitored throughout the term by the supervising faculty member and/or laboratory instructor, and feedback will be provided on teaching effectiveness. Students interested in pursuing an academic career are strongly encouraged to enroll. Students enrolled in this class are expected to participate in at least one DCAL workshop for graduate student teaching assistants prior to the term during which they enroll. Example workshops are as follows: Future faculty teaching workshop series (five-part workshop offered twice annually), campus-wide TA orientation (fall only), Learning Community for Future Faculty, Mentoring Series.

Prerequisites: Limited to PhD candidates with permission of research advisor and course instructor. Normally, students will elect this course in a term subsequent to passing the qualifying examination.

ENGG 296 Graduate Research 1

Offered: All Terms (Arrange)

Graduate research (1 credit) for MS and PhD students.

ENGG 297 Graduate Research 2

Offered: All Terms (Arrange)

Graduate research (2 credits) for MS and PhD students.

ENGG 298 Graduate Research 3

Offered: All Terms (Arrange)

Graduate research (3 credits) for MS and PhD students.

ENGG 299 Advanced Special Topics in Engineering Sciences

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

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. 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. The course is graded on a credit/no credit basis by the instructor after completion of the report. Students may enroll in an outside internship program with the support of their faculty advisor, as long as they maintain enrollment in their program or take an approved leave of absence. Students holding F-1 visa status will need to get an updated I-20 endorsed with employment authorization, prior to starting their internship. F-1 students should consult the Office of Visa and Immigration Services (OVIS) about the application process. Internships normally occur in the summer terms, are paid by the company, and should coincide with the start and end of the term. Students electing to do an internship and who are not taking a leave of absence must enroll in ENGG 300 to formalize their internship experience, complete an Internship proposal form (available in the Thayer Registrar's Office), and meet with the instructor prior to enrollment. During the internship a student is not generally funded by a stipend and the tuition and health insurance (if applicable) is funded through Thayer scholarship. Students in the PhD Innovation program should consult the policy & requirements for that program. 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.

Prerequisites: 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

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

Prerequisites: ENGS 34 and ENGS 105, or equivalent

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

Prerequisites: ENGS 33 and ENGS 105, or equivalent

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. (Cannot be used to satisfy any AB degree requirements)
Prerequisites: ENGS 105 and ENGS 120

ENGG 310 Advanced Topics in Signals and Systems

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. (Cannot be used to satisfy any AB degree requirements)
Prerequisites: Different for each topic; normally include ENGS 123 and ENGG 210 or equivalent, and permission of instructor

ENGG 312 Topics in Statistical Communication Theory

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. (Cannot be used to satisfy any AB degree requirements)
Prerequisites: ENGS 93, ENGS 110, and permission of instructor

ENGG 317 Topics in Digital Computer Design

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. (Cannot be used to satisfy any AB degree requirements)
Prerequisites: ENGS 116 and permission of instructor

ENGG 321 Advanced Innovation and Entrepreneurship

Offered: 22W, 23W

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 meetings, 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

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

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

ENGG 325 Introduction to Surgical Innovation

Offered: 21F, 22W, 22S, 22F, 23W, 23S, 23F

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

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 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 patient's 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 instructors.
Prerequisites: Permission of instructor(s)
Instructors: Mirza, Paulsen

ENGG 332 Topics in Plastic Flow and Fracture of Solids

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. (Cannot be used to satisfy any AB degree requirements)
Prerequisites: ENGS 130, ENGS 132, and permission of instructor

ENGG 339 Advanced Electron Microscopy

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. (Cannot be used to satisfy any AB degree requirements)
Prerequisites: ENGS 133 or permission of instructor

ENGG 365 Advanced Biomaterials

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. (Cannot be used to satisfy any AB degree requirements)
Prerequisites: ENGS 165 and permission of instructor
Instructor: Van Citters

ENGG 367 Heat Transfer in Hyperthermia

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. (Cannot be used to satisfy any AB requirements)
Prerequisites: ENGS 23, ENGS 156, and permission of instructor

ENGM 387 MEM Professional Skills

Offered: 21F, 22F, 23F

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. (Cannot be used to satisfy any AB, BE, MS, or PhD degree requirements)
No prerequisites

ENGG 390 Master of Engineering Management Project

Offered: All terms (Arrange)

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 Thayer research program.

Prerequisites: ENGM 178 or permission of instructor

ENGG 700 Responsible and Ethical Conduct of Research

Offered: 21F, 22F, 23F

For new MS & PhD students only.


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Inquiries or complaints concerning other forms of discrimination in the educational and employment context may be referred to Office of Institutional Diversity & Equity and/or the United States Equal Employment Opportunity Commission or New Hampshire Commission for Human Rights:

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