2020-2021

GUIDE TO PROGRAMS & COURSES

DARTMOUTH ENGINEERING

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Academic Calendar 2020-2021

engineering.dartmouth.edu/academics/calendar

FALL TERM 2020	
September 1–15	Virtual orientation for new students
September 13, Sunday	Fall term check-in
September 14, Monday	Fall term classes begin
September 23, Wednesday	Final day for delayed check-in
October 2–4, Friday–Sunday	Homecoming
November 17, Tuesday	Fall classes end at 5:20 p.m.; pre-examination break begins
Nov. 30–Dec. 3, Monday–Thursday	Fall term exams
WINTER TERM 2021	
January 6, Wednesday	Winter term check-in
January 7, Thursday	Winter term classes begin
January 16, Saturday	Final day for delayed check-in
January 18, Monday	Observance of Martin Luther King, Jr. Day (Classes moved to X-periods except 3A classes, which move to the 3B period on Tues., Jan. 19)
March 10, Friday	Winter term classes end at 5:20 p.m.; pre-examination break begins
March 13–17, Monday–Friday	Winter term examinations
SPRING TERM 2021	
March 28, Sunday	Spring term check-in
March 29, Monday	Spring term classes begin
April 7, Wednesday	Final day for delayed check-in
May 31, Monday	Memorial Day (College Holiday); no classes
June 2, Wednesday	Spring term classes end at 5:20 p.m.
June 3, Thursday	Pre-examination break
June 4–8, Friday–Tuesday	Spring term examinations
June 12, Saturday	Thayer School Investiture Ceremony
June 13, Sunday	Dartmouth Commencement Day
SUMMER TERM 2021 (TENTATIVE)	
June 23, Wednesday	Summer term check-in
June 24, Thursday	Summer term classes begin
June 27, Saturday	Special day of classes: courses meeting 10A period, 10:00; 2A period, 12:00; 3A/3B periods, 2:00. Courses regularly held in other time sequences do not meet.
July 5, Monday	Independence Day (College Holiday), no classes
July 9, Friday	Final day for delayed check-in
August 25, Wednesday	Summer term classes end at 5:20 p.m.; pre-examination break begins
August 28–31, Saturday–Tuesday	Summer term examinations

FACULTY

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Faculty

engineering.dartmouth.edu/people/faculty

EMERITI

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

Alvin Omar Converse, PhD
Professor of Engineering, Emeritus

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

Elsa Garmire, PhD
Sydney E. Junkins 1887 Professor, Emerita

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

Alexander Hartov
Professor of Engineering, Emeritus

Charles Edgar Hutchinson, PhD
Dean of Thayer School, Emeritus
John H. Krehbiel Sr. Professor for Emerging Technologies, Emeritus

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

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

Daniel R. Lynch, PhD
MacLean Professor of Engineering, Emeritus

Victor F. Petrenko, DSc
Research Professor, Emeritus

Horst J. Richter, Dr-Ing
Professor of Engineering, Emeritus

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

Graham B. Wallis, PhD
Sherman Fairchild Professor, Emeritus

ENDOWED PROFESSORSHIPS

George Austin Colligan Distinguished Professorship
Erland M. Schulson, PhD

Sherman Fairchild Professorship
Ian Baker, DPhil

Dorothy and Walter Gramm Professorship
George Cybenko, PhD

John H. Krehbiel Sr. Professor for Emerging Technologies
Eric Fossum, PhD

Barry L. MacLean Professorship
Brian W. Pogue, PhD

Robert A. Pritzker Chair in Biomedical Engineering
Keith Paulsen, PhD

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

Myron Tribus Professorship in Innovation
John P. Collier, DE

Hodgson Family Professorship within the
Arthur L. Irving Institue for Energy and Society
Geoffroy Hautier, PhD

Stata Family Career Development Professorship
Vikrant Vaze

ENDOWED EARLY CAREER PROFESSORSHIPS

William P. Harris Career Development Assistant Professorship
Weiyang (Fiona) Li, PhD

Ralph and Marjorie Crump Assistant Professorship
Jiwon Lee, PhD

Charles H. Gaut & Charles A. Norberg Professorship
Elizabeth Murnane, PhD

CORE FACULTY

Alexis R. Abramson, PhD
Dean and Professor of Engineering

Margie Ackerman, PhD
Professor of Engineering

Mary R. Albert, PhD
Professor of Engineering

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

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

Petr Brůža, PhD
Assistant Professor of Engineering

Zi Chen, PhD
Assistant Professor of Engineering

Benoit Cushman-Roisin, PhD
Professor of Engineering

George Cybenko, PhD
Dorothy and Walter Gramm Professor of Engineering

Scott C. Davis, PhD
Assistant Professor of Engineering

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

Amro Farid, PhD
Associate Professor of Engineering

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

Harold J. Frost, PhD
Associate Professor of Engineering

Tillman U. Gerngross, PhD
Professor of Engineering

Karl Griswold, PhD
Associate Professor of Engineering

Ryan J. Halter, PhD
Associate Professor of Engineering

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

Geoffroy Hautier
Hodgson Family Associate Professor of Engineering

Joseph J. Helble, PhD
Professor of Engineering
Provost, Dartmouth College

Shudong Jiang, PhD
Professor of Engineering

Eugene Korsunskiy, MFA
Assistant Professor of Engineering

Ronald C. Lasky, PhD
Professor of Engineering

Mark Laser, PhD
Associate Professor of Engineering

Jiwon Lee, PhD
Ralph and Marjorie Crump Assistant Professor of Engineering

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

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

Yan Li, PhD
Assistant Professor of Engineering

Jifeng Liu, PhD
Associate Professor of Engineering

Geoffrey P. Luke, PhD
Assistant Professor of Engineering

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

Vicki May, PhD
Professor of Engineering

Matthew D.J. McGarry, PhD
Assistant Professor of Engineering

Paul M. Meaney PhD
Professor of Engineering

Colin R. Meyer, PhD
Assistant Professor of Engineering

Sohail K. Mirza, MD
Professor of Engineering
Professor and Chair of Orthopaedics, Geisel School of Medicine

Elizabeth Murnane, PhD
Charles H. Gaut & Charles A. Norberg Assistant Professor of Engineering

Kofi Odame PhD
Associate Professor of Engineering

Daniel G. Olson PhD
Assistant Professor of Engineering

Geoffrey P. Parker, PhD
Professor of Engineering
Director, MEM Programs

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

Donald K. Perovich, PhD
Professor of Engineering

Minh Q. Phan, PhD
Associate Professor of Engineering

Brian W. Pogue, PhD
MacLean Professor of Engineering
Director, MS and PhD Programs
Professor of Physics and Astronomy
Professor of Surgery, Geisel School of Medicine

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

Peter J. Robbie, MFA
Associate Professor of Engineering

Kimberly Samkoe, PhD
Associate Professor of Engineering

Eugene Santos, Jr., PhD
Professor of Engineering

Rahul Sarpeshkar, PhD
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, PhD
Assistant Professor of Engineering

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

Simon G. Shepherd, PhD
Associate Professor of Engineering

Fridon Shubitidze, PhD
Associate Professor of Engineering

Jason Stauth, PhD
Associate Professor of Engineering

Charles R. Sullivan, PhD
Professor of Engineering

Stephen Taylor, PhD
Professor of Engineering

B. Stuart Trembly, PhD
Associate Professor of Engineering

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

Vikrant Vaze, PhD
Stata Family Career Development Associate Professor of Engineering

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

ADJUNCT AND VISITING FACULTY

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

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

Benjamin Barrowes, PhD
Research Physicist, U.S. Army Cold Regions Research and Engineering Laboratory
Adjunct Assistant Professor of Engineering

Eric Bish, PhD
Visiting Assistant Professor

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

Chi-Yang Cheng, PhD
Professor of Medicine, Geisel School of Medicine
Adjunct Associate Professor of Engineering

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

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

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

Jonathan T. Elliot, PhD
Adjunct Assistant Professor of Engineering

Jeremy Faludi PhD, LEED, AP BD+C
Adjunct Assistant Professor of Engineering

David J. Gladstone, ScD
Associate Professor of Medicine, Geisel School of Medicine
Adjunct Associate Professor of Engineering

Oliver Goodenough, JD
Professor, Vermont Law School
Adjunct Professor of Engineering

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

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

Jane Hill, PhD
Adjunct Associate Professor of Engineering

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

Michael Jermyn, PhD
Adjunct Assistant Professor of Engineering

Songbai Ji, DSc
Adjunct Associate Professor of Engineering

Stephen C. Kanick, PhD
Adjunct Assistant Professor of Engineering

Erik J. Kobylarz, MD, PhD
Department of Neurology Dartmouth-Hitchcock Medical Center
Adjunct Associate Professor of Engineering

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

Michael B. Mayor, MD
William N. and Bessie Allyn Professor of Orthopaedic Surgery, Geisel School of Medicine
Adjunct Professor of Engineering

Kevin O'Neill, PhD
Research Civil Engineer, U.S. Army Cold Regions Research and Engineering Laboratory
Adjunct Professor

Ulf Osterberg, PhD
Visiting Professor of Engineering

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

Christopher Polashenski, PhD
Research Geophysicist, U.S. Army Cold Regions Research and Engineering Laboratory
Adjunct Assistant Professor of Engineering

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

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

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

Scott A. Snyder, PhD
Adjunct Assistant Professor

Rafe Steinhauer, PhD
Visiting Assistant Professor and Lecturer

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

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

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

LECTURERS

Ryan Chapman, PhD
Post-Doctoral Research Associate and Lecturer

Daniel C. Cullen, PhD
Project Lab, Materials Lab, Fluids Lab Manager

Ross Gortner, MEM
Associate Director, MEM Program

Kendall Hoyt, PhD
Assistant Professor of Medicine, Geisel School of Medicine

David Macaulay, BArch
Author and Artist

Steven Peterson, MS
Independent Consultant

Markus Testorf, PhD
Lecturer

John D. Wilson, MArch
Senior Lecturer, Studio Art

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Undergraduate Studies

engineering.dartmouth.edu/academics/undergraduate

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

ENGINEERING DEGREE PROGRAMS

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

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

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

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

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

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

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

engineering.dartmouth.edu/academics/undergraduate/dual

PREREQUISITES

All engineering sciences majors, minors, and modified majors take 7 courses in mathematics, physics, computer science, and chemistry. First-year students should take the placement test in mathematics during orientation week. Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

ENGINEERING SCIENCES CURRICULUM

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

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

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

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

ADVANCE PLANNING FOR THE MEM DEGREE

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

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

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

GRADE STANDARDS

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

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

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

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

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

HONORS PROGRAM

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

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

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

ACADEMIC HONOR

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

dartmouth.edu/~uja/honor

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

FOREIGN STUDY

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

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

Bachelor of Arts (AB)

engineering.dartmouth.edu/academics/undergraduate/ab

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

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

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

www.dartmouth.edu/~reg

AB ENGINEERING SCIENCES PROGRAMS

DEGREE PROGRAM	BASIC MAJOR REQUIREMENTS	TOTAL	SEE PAGE
Engineering Sciences major	9-10 engineering sciences courses, including a culminating experience	9-10	20
Biomedical Engineering Sciences major	5 engineering sciences courses 4 biology and chemistry courses 1 biochemistry or engineering sciences elective Culminating experience in either engineering sciences of biochemistry	11	21
Engineering Physics major	5 engineering sciences courses 5 physics courses Culminating experience in EITHER engineering sciences OR physics	10	23
Engineering Sciences major modified by another discipline	6-7 courses in engineering sciences including a culminating experience 4 courses in the other discipline	10-11	24–35
Engineering Sciences minor	5 courses in math and physics plus 5 courses in engineering sciences	10	36
Human-Centered Design minor	2 engineering sciences courses 4 courses in other discipline	6	37
Materials Science minor	4 materials science courses 6 courses in chemistry, physics, OR engineering sciences	10	38
Major modified by Engineering Sciences	3-4 courses in math and physics plus 4 courses in engineering sciences	7-8	39

Culminating Experience

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

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

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

ENGINEERING AS A FOUNDATION FOR PROFESSIONAL FIELDS

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

PROFESSIONAL FIELD	MAJOR	SEE PAGE
Architecture	Engineering Sciences major modified with Studio Art	35
Biomedical engineering	Biomedical Engineering Sciences major	22
Biotechnology	Engineering Sciences major modified with Biology	24
Chemical engineering	Engineering Sciences major modified with Chemistry	25
Computer engineering	Engineering Sciences major modified with Computer Science	26
Environmental engineering	Engineering Sciences major modified with Environmental Sciences	29
Any engineering field or interdisciplinary engineering	Engineering Sciences major	21
Engineering physics	Engineering Physics major	23
Geology	Engineering Sciences major modified with Earth Sciences	27
Human-centered design	Human-Centered Design minor	37
Management and financial engineering	Engineering Sciences major modified with Economics	28
Materials science	Materials Science minor with Chemistry or Physics major	38
Medicine	Biomedical Engineering Sciences major	22
Neuroscience	Engineering Sciences major modified with Neuroscience	31
Product design	Engineering Sciences major modified with Studio Art	35
Technology in public policy	Engineering Sciences modified with Public Policy	33

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

ENGINEERING SCIENCES MAJOR

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

PREREQUISITES			
Mathematics		MATH 3 Introduction to Calculus	3 courses
		MATH 8 Calculus of Functions of One and Several Variables	
		MATH 11 Multivariable Calculus for Two-Term Advanced Placement First-Year Students OR MATH 13 Calculus of Vector-Valued Functions	
Physics		PHYS 13, 14 Introductory Physics I, II	2 courses
Chemistry		CHEM 5 General Chemistry	1 course
Computer Science (choose 1 option)		ENGS 20 Introduction to Scientific Computing*	1-2 courses
		COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	
REQUIRED COURSES			
Common core courses		ENGS 21 Introduction to Engineering**	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	
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 the engineering sciences option or one from each option)	**Engineering sciences option**	Any engineering sciences (ENGS) course above ENGS 20 (excluding ENGS 87)	2 courses
	Science/math option	ASTR 15 and above; BIOL 12 and above (except 52); CHEM 6, 10 and above (except 63); EARS 31, 33, 35, 37, 40-52, 59, 62, 64, 66-75, 79 and above; ENVS 30 and 79; MATH 17 – 29, 31, 32, 35, 38, 39, 40, 42, 43, 50 and above; PHYS 19 or 40 (formerly 24), 41 and above (except 48); COSC 30, 31, 39, 49, 71, 74	
Culminating experience		Thesis, design project, or advanced course (see page 19)	

For advice, contact the chair of Engineering Sciences, Professor Douglas Van Citters.

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

** Should be taken sophomore year.

BIOMEDICAL ENGINEERING SCIENCES MAJOR

The biomedical engineering sciences major is offered to students interested in medical school. Faculty at Thayer and Geisel School of Medicine at Dartmouth jointly advise students on research. Geisel offers accomplished students in this major the opportunity apply for admission through the Early Assurance Program. For more information, visit:

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

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

PREREQUISITES			
Mathematics	MATH 3 Introduction to Calculus		3 courses
	MATH 8 Calculus of One and Several Variables		
	MATH 13 Calculus of Vector-Valued Functions OR MATH 11 Multivariable Calculus for Two-Term Advanced Placement First-Year Students		
Chemistry	CHEM 5–6 General Chemistry OR CHEM 10 Honors First-Year Chemistry		1–2 courses
Physics	PHYS 13, 14 Introductory Physics I, II		2 courses
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing*		1-2 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***		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 30 Biological Physics	
		ENGS 35 Biotechnology and Biochemical Engineering	
		ENGS 36 Chemical Engineering	
Engineering course (choose 1)	ENGS 56 Biomedical Engineering OR 1 additional course from ENGS 23–26		1 course
Biology courses (choose 2)	BIOL 12 Cell Structure and Function		2 courses
	BIOL 13 Gene Expression and Inheritance		
	BIOL 14 Physiology		
Chemistry courses	CHEM 51–52 Organic Chemistry OR CHEM 57–58 Organic Chemistry		2 courses
Elective (choose 1)**	Engineering Sciences course numbered above ENGS 23		1 course
	BIOL 40 Biochemistry		
	CHEM 41 Biological Chemistry		
Culminating experience	Thesis or advanced course (see page 19)		

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

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

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

*** Should be taken sophomore year.

ENGINEERING PHYSICS MAJOR

The departments of Engineering Sciences and Physics and Astronomy offer the major in Engineering Physics. Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

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

For advice, contact Professor Jifeng Liu.

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

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

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

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

ENGINEERING SCIENCES MODIFIED WITH BIOLOGY

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions	3 courses
Physics	PHYS 13, 14 Introduction to Physics I, II	2 courses
Chemistry (choose 1)	CHEM 5 General Chemistry CHEM 10 Honors First-Year General Chemistry	1 course
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	1 course
Biology	BIOL 12 Cell Structure and Function	1 course
REQUIRED COURSES		
Engineering core courses	ENGS 22 Systems ENGS 25 Introduction to Thermodynamics ENGS 35 Biotechnology and Biochemical Engineering	3 courses
Engineering electives (choose 3)	ENGS 21 Introduction to Engineering** ENGS 23 Distributed Systems and Fields ENGS 24 Science of Materials ENGS 26 Control Theory ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics ENGS 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	3 courses
Biology core course	BIOL 13 Gene Expression and Inheritance	1 course
Biology or chemistry electives (choose 3)	BIOL 37 Endocrinology 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	3 courses
Culminating experience	Thesis, design project, or advanced course (see page 19)	

For advice, contact Professor Lee Lynd.

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

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH CHEMISTRY

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions	3 courses
Physics	PHYS 13, 14 Introductory Physics I, II	2 courses
Chemistry	CHEM 5-6 General Chemistry OR CHEM 10 Honors First-Year General Chemistry	1-2 courses
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	1 course
REQUIRED COURSES		
Engineering core courses	ENGS 22 Systems ENGS 25 Introduction to Thermodynamics ENGS 36 Chemical Engineering	3 courses
Engineering electives (choose 3 with not more than 2 from 21, 35, and 37 counting toward the major)	ENGS 21 Introduction to Engineering ENGS 23 Distributed Systems and Fields ENGS 24 Science of Materials ENGS 26 Control Theory ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics ENGS 35 Biotechnology and Biochemical Engineering ENGS 37 Introduction to Environmental Engineering ENGS 52 Introduction to Operations Research ENGS 91 Numerical Methods in Computation ENGS 156 Heat, Mass, and Momentum Transfer ENGS 158 Chemical Kinetics and Reactors	3 courses
Chemistry core courses	CHEM 51 Organic Chemistry OR CHEM 57 Honors Organic Chemistry CHEM 75 Physical Chemistry I	2 courses
Chemistry electives (choose 2)	CHEM 41 Biological Chemistry I CHEM 52 Organic Chemistry OR 58 Honors Organic Chemistry CHEM 63 Environmental Chemistry CHEM 64 Basic Inorganic Chemistry CHEM 67 Physical Biochemistry I CHEM 76 Physical Chemistry II	2 courses
Culminating experience	Thesis, design project, or advanced course (see page 19)	

For advice, contact Professor Lee Lynd.

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

ENGINEERING SCIENCES MAJOR MODIFIED WITH COMPUTER SCIENCE

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

PREREQUISITES			
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions		3 courses
Physics	PHYS 13, 14 Introductory Physics I, II		2 courses
Chemistry	CHEM 5 General Chemistry		1 course
Computer Science	COSC 1 Introduction to Programming and Computation or ENGS 20 Introduction to Scientific Programming COSC 10 Problem Solving via Object-Oriented Programming		2 courses
REQUIRED COURSES			
Engineering core courses **(all of Group 1; choose 1 from Group 2)**	**Group 1**	ENGS 22 Systems ENGS 27 Discrete and Probabilistic Systems ENGS 31 Digital Electronics	4 courses
	Group 2	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 including at least 1 from each group and 3 in Computer Science)**	**Group 1**	ENGS 32 Electronics: Introduction to Linear and Digital Circuits ENGS 62 Microprocessors in Engineered Systems COSC 51 Computer Architecture	5 courses
	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	Thesis, design project, or advanced course (see page 19)		

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

ENGINEERING SCIENCES MAJOR MODIFIED WITH EARTH SCIENCES

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds.

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions	3 courses
Physics	PHYS 13, 14 Introductory Physics I, II	2 courses
Chemistry	CHEM 5 General Chemistry	1 course
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	1 course
Earth Sciences	1 introductory Earth Sciences course from EARS 1–9, exclusive of EARS 7 EARS 40 Materials of the Earth	2 courses
REQUIRED COURSES		
Engineering Sciences	ENGS 22 Systems ENGS 23 Distributed Systems and Fields ENGS 24 Science of Materials ENGS 25 Introduction to Thermodynamics 2 Engineering Sciences electives	6 courses
Earth Sciences	Four Earth Sciences 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	Thesis, design project, or advanced course (see page 19)	

For advice, contact Professor Erland Schulson.

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

ENGINEERING SCIENCES MAJOR MODIFIED WITH ECONOMICS

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds. Students interested in completing the BE in a 5th year of study are advised to take at least 3 additional BE-eligible courses in engineering, science, or math as part of their AB plans.

PREREQUISITES			
Mathematics		MATH 3 Introduction to Calculus	3 courses
		MATH 8 Calculus of Functions of One and Several Variables	
		MATH 13 Calculus of Vector-Valued Functions	
Physics		PHYS 13, 14 Introductory Physics I, II	2 courses
Chemistry		CHEM 5 General Chemistry	1 course
Computer Science (choose 1 option)		ENGS 20 Introduction to Scientific Computing*	1-2 courses
		COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	
Economics		ECON 1 The Price System: Analysis, Problems, and Policies	2 courses
		ECON 10 Introduction to Statistical Methods	
REQUIRED COURSES			
Engineering core courses		ENGS 21 Introduction to Engineering**	3 courses
		ENGS 22 Systems	
		ENGS 52 Introduction to Operations Research (Prerequisite is Math 22)	
Engineering electives (choose 1 from Group 1; 2 from Group 2)	**Group 1**	ENGS 23 Distributed Systems and Fields	3 courses
		ENGS 24 Science of Materials	
		ENGS 25 Introduction to Thermodynamics	
		ENGS 33 Solid Mechanics	
	Group 2	Any other Engineering Sciences course that counts toward the AB	
Economics courses (choose 2)		ECON 20 Econometrics	2 courses
		ECON 21 Microeconomics	
		ECON 22 Macroeconomics	
Economics electives (choose a 2-course sequence from a single group)	**Money and Finance**	ECON 26 The Economics of Financial Intermediaries and Markets	2 courses
		ECON 36 Theory of Finance	
	Industrial Organization	ECON 25 Industrial Organization and Public Policy	
		ECON 35 Games and Economic Behavior OR ECON 45 Topics in Industrial Organization	
	International Trade	ECON 29 International Finance and Open-Economy Macroeconomics	
		ECON 39 International Trade	
Culminating experience		Thesis, design project, or advanced course (see page 19)	

For advice, contact Professor Geoffrey Parker.

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

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH ENVIRONMENTAL SCIENCES

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds. Students interested in completing the BE in a 5th year of study are advised to take at least 3 additional BE-eligible courses in engineering, science, or math as part of their AB plans.

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

continued

ENGINEERING SCIENCES MAJOR MODIFIED WITH ENVIRONMENTAL SCIENCES cont.

REQUIRED COURSES			
Environmental Sciences courses **(choose 4, including at least 2 from a single department)**	**Biology**	BIOL 21 Population Ecology OR BIOL 51 Advanced Population Ecology	4 courses
		BIOL 22 Methods in Ecology	
		BIOL 25 Introductory Marine Biology and Ecology	
		BIOl 26 Global Change Policy	
		BIOL 27 Animal Behavior	
	Chemistry	CHEM 51 Organic Chemistry (only as prerequisite to CHEM 63)	
		CHEM 63 Environmental Chemistry	
	Earth Sciences	EARS 16 Hydrology and Water Resources	
		EARS 35 The Soil Resource	
		EARS 71 River Processes and Watershed Science	
		EARS 66 Hydrogeology	
		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 Ecological Agriculture	
		ENVS 30 Global Environmental Science	
		ENVS 53 Science for Sustainable Systems	
Culminating experience	Thesis, design project, or advanced course (see page 19)		

For advice, contact Professor Benoit Cushman-Roisin or Professor Lee Lynd.

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

ENGINEERING SCIENCES MODIFIED WITH NEUROSCIENCE

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds. Students interested in completing the BE in a 5th year of study are advised to take at least 3 additional BE-eligible courses in engineering, science, or math as part of their AB plans.

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions	3 courses
Physics	PHYS 13, 14 Introductory Physics I, II	2 courses
Chemistry	CHEM 5 General Chemistry	1 course
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	1-2 courses
Neuroscience	PSYC 6 Introduction to Neurosciences	1 course
REQUIRED COURSES		
Engineering core courses	ENGS 21 Introduction to Engineering** 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	4 courses
Engineering electives (choose 2)	ENGS 26 Control Theory (if not taken above) 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	2 courses

continued

ENGINEERING SCIENCES MODIFIED WITH NEUROSCIENCE cont.

REQUIRED COURSES		
Neuroscience core courses (choose 2)	PSYC 45 Behavioral Neuroscience PSYC 46 Cellular and Molecular Neuroscience PSYC 65 Systems Neuroscience (formerly Physiology of Behavior)	2 courses
Neuroscience electives (choose 2)	PSYC 21 Perception PSYC 27 Cognitive Neuroscience PSYC 40 Introduction to Computational Neuroscience PSYC 60 Principles of Human Brain Mapping with fMRI BIOL 27 Animal Behavior PSYC 80–87 Seminars in Neuroscience (allow one seminar only as one of the two electives)	2 courses
Culminating experience	Thesis, design project, or advanced course (see page 19)	

For advice, contact Professor Laura Ray.

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

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH PUBLIC POLICY

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds. Students interested in completing the BE in a 5th year of study are advised to take at least 3 additional BE-eligible courses in engineering, science, or math as part of their AB plans.

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions	3 courses
Physics	PHYS 13, 14 Introductory Physics I, II	2 courses
Chemistry	CHEM 5 General Chemistry	1 course
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	1-2 courses
Statistical data analysis (choose 1)	ECON 10 Introduction to Statistical Methods GOVT 10 Quantitative Political Analysis SOCY 10 Quantitative Analysis of Social Data MATH 10 Introductory Statistics	1 course

REQUIRED COURSES			
Engineering core courses		ENGS 21 Introduction to Engineering** ENGS 22 Systems	2 courses
Engineering electives (choose 1 from each group)	**Group 1**	ENGS 23 Distributed Systems and Fields ENGS 24 Science of Materials ENGS 25 Introduction to Thermodynamics ENGS 26 Control Theory ENGS 27 Discrete and Probabilistic Systems	4 courses
	Group 2	ENGS 30 Biological Physics ENGS 31 Digital Electronics ENGS 32 Electronics: Introduction to Linear and Digital Circuits ENGS 33 Solid Mechanics ENGS 34 Fluid Dynamics ENGS 35 Biotechnology and Biochemical Engineering ENGS 36 Chemical Engineering ENGS 37 Introduction to Environmental Engineering	
	Group 3	ENGS 41 Sustainability and Natural Resources Management ENGS 43 Environmental Transport and Fate ENGS 44 Sustainable Design ENGS 52 Introduction to Operations Research ENGS 56 Introduction to Biomedical Engineering	
	Group 4	Any ENGS course numbered above 20 (excluding ENGS 80 and 87)	

continued

ENGINEERING SCIENCES MAJOR MODIFIED WITH PUBLIC POLICY cont.

REQUIRED COURSES			
Public Policy **(choose 4 with at least 1 from each group)**	**Group 1**	PBPL 5 Introduction to Public Policy	4 courses
	Group 2	PBPL 40 Economics of Public Policymaking	
		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 Resourses and Public Policy, Science/Technology and Public Policy	
Culminating experience	Thesis, design project, or advanced course (see page 19)		

For advice, contact Provost Joseph Helble.

Information on Public Policy courses and tracks is at:

rockefeller.dartmouth.edu/public-policy/public-policy-minor

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

** Should be taken sophomore year.

ENGINEERING SCIENCES MAJOR MODIFIED WITH STUDIO ART

Prerequisite courses to the major can be taken under the Non-Recording Option with the exception of those that are out of bounds. Students interested in completing the BE in a 5th year of study are advised to take at least 3 additional BE-eligible courses in engineering, science, or math as part of their AB plans.

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions	3 courses
Physics	PHYS 13, 14 Introductory Physics I, II	2 courses
Chemistry	CHEM 5 General Chemistry	1 course
Computer Science (choose 1 option)	ENGS 20 Introduction to Scientific Computing* COSC 1 Introduction to Programming and Computation AND COSC 10 Problem Solving via Object-Oriented Programming	1 course
REQUIRED COURSES		
Engineering core courses	ENGS 21 Introduction to Engineering** ENGS 22 Systems ENGS 24 Science of Materials ENGS 33 Solid Mechanics	4 courses
Engineering electives	Any 2 engineering sciences courses available for AB credit in the major.	2 courses
Studio Art core courses	SART 15 Drawing I SART 16 Sculpture I	2 courses
Studio Art electives	Any upper level Studio Art course	2 courses
Culminating experience	Thesis, design project, or advanced course (see page 19)	

For advice, contact Professor Peter Robbie.

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

** Should be taken sophomore year.

ENGINEERING SCIENCES MINOR

Students should note that many Engineering Sciences courses require prerequisites in addition to those noted. No courses other than those used as prerequisites to the minor may be taken under the Non-Recording Option to satisfy requirements of the minor. Courses used in the major cannot be used to satisfy requirements of the minor.

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus MATH 8 Calculus of Functions of One and Several Variables MATH 13 Calculus of Vector-Valued Functions	3 courses
Physics	PHYS 13 Introductory Physics I 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 ENGS 21 Introduction to Engineering ENGS 22 Systems	3 courses
Electives (choose 2)	Any engineering sciences undergraduate course numbered above 20 (excluding 80 and 87)	2 courses

For advice, contact the chair of Engineering Sciences, Professor Douglas Van Citters.

HUMAN-CENTERED DESIGN MINOR

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

PREREQUISITES		
Mathematics	MATH 3 Introduction to Calculus	1 course
Design Foundation	ENGS 12 Design Thinking ENGS 21 Introduction to Engineering*	2 courses
REQUIRED COURSES		
Ethnographic Methods and Human Factors (Psychology)	ANTH 3 Intro to Cultural Anthropology ANTH 18 Intro to Research Methods in Cultural Anthropology ANTH 56 Intro to Research Methods in Medical Anthropology SOCY 11 Research Methods GEOG 11 Qualitative Methods and the Research Process in Geography PSYC 21 Perception PSYC 22 Learning PSYC 23 Social Psychology PSYC 27 Cognitive Neuroscience PSYC 28 Cognition PSYC 40 Intro to Computational Neuroscience PSYC 43 Emotion PSYC 51.11 Thinking About Thinking	2 courses
Design electives	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 25.01 UI/UX Design I COSC 25.02 UI/UX Design II COSC 27 Projects in Digital Arts COSC 28 Advanced Projects in Digital Arts COSC 29.04/PBS 15 Impact Design COSC 29.05 UI/UX Design FILM 51 Game Design PBPL 43 Social Entrepreneurship SART 65 Architecture I SART 66 Architecture II SART 68 Architecture III Independent Study in a relevant discipline	2 courses

Students may substitute relevant courses in section 2 (that cover ethnographic methodology or human factors psychology) and 3 (that focus on problem-solving of human needs and result in the creation of artifacts) with prior approval from the Faculty Advisor and the Undergraduate Curriculum Committee (Engineering Sciences). Before taking courses in section 3, it is recommended that students complete both courses in section 1 plus at least one course from section 2.

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

* Should be taken sophomore year.

** For Engineering Majors: If ENGS 44 or ENGS 75 is selected for the minor, it may not be counted toward the major.

MATERIALS SCIENCE MINOR

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

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

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

For advice, contact the chair of Engineering Sciences, Professor Douglas Van Citters.

OTHER MAJOR MODIFIED WITH ENGINEERING SCIENCES

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

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

For advice, contact the chair of Engineering Sciences, Professor Douglas Van Citters, and the chair of the department of the major.

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

** Should be taken sophomore year.

Bachelor of Engineering (BE)

engineering.dartmouth.edu/academics/undergraduate/be

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

PROGRAM EDUCATIONAL OBJECTIVES

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

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

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

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

ENROLLMENT

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

- 2019–2020: 65 students
- 2018–2019: 76 students
- 2017–2018: 58 students
- 2016–2017: 81 students
- 2015–2016: 58 students

GRADUATION

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

RESIDENCY

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

NUMBER OF COURSES

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

BE REQUIREMENTS

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

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

Detailed information about specific courses that satisfy accreditation and Thayer School requirements is in the Bachelor of Engineering Program Plan, available at:

www.dartmouth.edu/bannerstudent

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

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

BE ADVISORS

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

Dual-Degree Program

engineering.dartmouth.edu/academics/undergraduate/dual

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

Sample AB/BE Programs

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

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

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

Undergraduate Admissions

AB ADMISSIONS

Admission to the AB program is through the:

Dartmouth Admissions Office,
McNutt Hall, Hanover, NH 03755.

www.dartmouth.edu/admissions

BE ADMISSIONS

Admission Requirements

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

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

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

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

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

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

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

Application Procedure

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

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

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

engineering.admissions@dartmouth.edu

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

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

Prospective students from other parts of the world should call:

1-603-646-2606

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

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

engineering.admissions@dartmouth.edu

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

Tuition and Expenses

Tuition for the 2019–2020 academic year is $19,265 per term, which covers instruction, use of instructional facilities, and health care service through the College infirmary.

Students without their own hospital coverage must purchase a Dartmouth College hospital insurance policy for approximately $3,891 per year.

The total cost of a year in the BE program, including tuition, books, room, board, and incidentals, is approximately $70,000–74,000 for the academic year 2020–2021. Financial aid can significantly lower the yearly cost.

Financial Aid

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

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

profileonline.collegeboard.com

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

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

HOURLY TEACHING ASSISTANTSHIPS AND OTHER EMPLOYMENT

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

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

PARTIAL TUITION SCHOLARSHIPS

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

LOANS

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

fafsa.ed.gov

Registration

RESIDENCY

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

CHECK-IN

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

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

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

COURSE CHANGES

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

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

WITHDRAWAL

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

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

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

REFUND POLICY

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

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

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

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Graduate Studies

Master of Engineering Management (MEM)

mem.dartmouth.edu

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

CURRICULUM

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

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

PREREQUISITES

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

ACADEMIC HONOR

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

RESIDENCY

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

NUMBER OF COURSES

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

INTERNSHIP

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

GRADE STANDARDS

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

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

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

INDUSTRY PARTNERS

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

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

MEM COURSE REQUIREMENTS

Engineering management core courses	ENGS 93: Statistical Methods in Engineering	8 courses
	ENGM 178: Technology Assessment	
	ENGM 180: Accounting and Finance	
	ENGM 181: Marketing	
	ENGM 183: Operations Management	
	ENGM 1XX: Strategy and Organizational Behavior	
	ENGM 387: MEM Professional Skills	
	ENGG 390: MEM Project/Internship	
Applied mathematics (choose 2)	ENGG 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 engineering sciences or engineering course	4 courses
	Business and management courses from Tuck School*	
	Graduate courses from Dartmouth science departments	
	Courses from Geisel School of Medicine	
	Environmental law courses from Vermont Law School	
TOTAL		14 courses

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

Popular Engineering Elective Courses

- ENGM 182: Data Analytics
- ENGM 188: Law for Technology and Entrepreneurship
- ENGM 186: Technology Project Management
- ENGG 103: Operations Research
- ENGM 185: Topics in Manufacturing Design and Processes
- ENGS 108: Applied Machine Learning
- ENGM 187: Technology Innovation and Entrepreneurship
- ENGS 174: Energy Utilization
- ENGS 171: Industrial Ecology

Popular Business Elective Courses

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

Typical Standard MEM Program Sequence (BS to MEM)

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

Fall	ENGS 93: Statistics
	ENGM 181: Marketing
	ENGM 178: Technology Assessment
	ENGM 387: MEM Professional Skills
Winter	ENGM 183: Operations Management
	Elective
	Elective
Spring	ENGS 180-1: Accounting
	ENGS 180-2: Finance
	Elective
	Elective
Summer	ENGG 390: MEM Project/Internship
Fall	Elective
	ENGM 179-1: Organizational Behavior
	ENGM 179-2: Strategy

MEM PROGRAM OPTIONS

Standard MEM Degree

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

BE+MEM Joint Degree

Students enrolled in Dartmouth's BE program (Dartmouth AB/BE and Dual-Degree students) who wish to build out their technical management knowledge should consider applying to the MEM program. BE+MEM students work towards both degrees simultaneously, typically reducing the time needed to complete both degrees by one term. Students are encouraged to apply to the MEM program during their senior year.

MEM+MBA Joint Degree

For students interested in a broader business curriculum the joint MEM+MBA degree option is available. Students enrolling in the MEM/MBA joint degree program can complete both degrees is as little as 2.5 years. Students must apply and be admitted to both programs, and it is recommended that students begin their studies in the MBA program. All requirements for the degree 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

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

MEM PROGRAM DIRECTORS

Geoffrey G. Parker, PhD
Director
Professor of Engineering

Ross A. Gortner, MEM
Associate Director

ENGINEERING FACULTY

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

Eric R. Fossum, PhD
Professor of Engineering

Oliver Goodenough, JD
Adjunct Professor of Engineering
Professor, Vermont Law School

Ryan Halter, PhD
Associate Professor of Engineering

Mark Laser, PhD
Associate Professor of Engineering

Ronald C. Lasky, PhD
Professor of Engineering

Keith Paulsen, PhD
Robert A. Pritzker Chair in Biomedical Engineering

Vikrant Vaze, PhD
Assistant Professor of Engineering

TUCK SCHOOL OF BUSINESS FACULTY

Laurens Debo, PhD
Associate Professor of Business Administration

Richard C. Sansing, PhD
Noble Foundation Professor of Accounting

Felipe Severino, PhD
Assistant Professor of Business Administration

Master of Engineering (MEng)

engineering.dartmouth.edu/academics/graduate/meng

The Master of Engineering (MEng) program is designed around tracks centered on professional areas of activity and intended for engineers already in the profession seeking to add depth to their knowledge or acquire new specialized knowledge. The programs offers tracks in 6 focus areas: Biological/Chemical, Biomedical, Electrical, Energy, Materials Science, Mechanical engineering.

The MEng program:

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

Candidates for the degree acquire:

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

Students have the option of completing all the requirements in 3 terms, taking 3 courses at a time, or following a schedule that fits their professional obligations. Need-based financial aid is offered up to 40% of tuition (See page 78).

QUALIFICATION FOR ADMISSION

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

ACADEMIC HONOR

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

RESIDENCY AND PROGRAM DURATION

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

COURSE REQUIREMENTS

Students enrolled in the MEng program are expected to follow one pre-defined specialization track and must select a total of 9 courses under each track, **5 of which should be from the list of the track's Core Courses.** The remaining four electives may be chosen from any graduate-level engineering or science course or suitable alternatives with advisor approval. Within their first week of enrollment students are required to submit a course plan to be approved by the MS-PhD Committee. For students with no engineering background, additional courses may be required. Thayer School's AB/BE students may not double-count courses towards the MEng degree.

GRADE STANDARDS

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

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

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

ADVISORS

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

ADDITIONAL GUIDELINES

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

BIOLOGICAL/CHEMICAL ENGINEERING TRACK

Core Courses

- ENGS 108: Applied Machine Learning
- ENGS 150: Intermediate Fluid Mechanics
- ENGS 155: Intermediate Thermodynamics
- ENGS 156: Heat, Mass, and Momentum Transfer
- ENGS 157: Chemical Process Design
- ENGS 158: Chemical Kinetics and Reactors
- 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 260: Advances in Biotechnology
- ENGG 261: Biomass Energy Systems
- ENGS 262: Advanced Biological Circuit Engineering
- COSC 175: Introduction to Bioinformatics (Applied Math)
- BIOC 101: Molecular Information in Biological Systems

Example Non-Engineering Courses

- COSC 174: Machine Learning and Statistical Data Analysis1
- COSC 186: Computational Structural Biology
- COSC 189: Topics in Computational Immunology
- 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 Learning1
- QBS 120: Foundations of Biostatistics I: Statistical Theory for the Quantitative Biomedical Sci.
- QBS 121: Foundations of Biostatistics II: Regression
- QBS 149: Mathematics and Probability for Statistics and Data Mining
- QBS 175: Foundations of Bioinformatics II2
- CHEM 101.2: Statistical Thermodynamics
- CHEM 161.2: Biomolecular Simulations
- CHEM 161.4: Structure and Dynamics of Biomolecules

Notes

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, and only one may be taken for credit.

BIOMEDICAL ENGINEERING TRACK

Core Courses

- ENGS 111: Digital Image Processing
- ENGG 113: Image Visualization and Analysis
- ENGS 129: Biomedical Circuits and Systems
- ENGS 156: Heat, Mass and Momentum Transfer
- ENGS 159: Molecular Sensors & Nanodevices in Biomedical Engineering
- ENGS 162: Basic Biological Circuit Engineering
- ENGS 165: Biomaterials
- ENGG 166: Quantitative Human Physiology
- ENGS 167: Medical Imaging
- ENGG 168: Biomedical Radiation Transport
- ENGS 169: Intermediate Biomedical Engineering
- ENGG 199: Advanced Imaging
- ENGS 262: Advanced Biological Circuit Engineering
- ENGG 325: Introduction to Surgical Innovation
- ENGG 365: Advanced Biomaterials

Additional Courses

- 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

ELECTRICAL ENGINEERING TRACK

Core Courses

Electronic Systems

- ENGS 125: Power Electronics and Electromechanical Energy Conversion
- ENGS 128: Advanced Digital System Design
- ENGS 129: Biomedical Circuits and Systems

Signal Processing

- ENGS 110: Signal Processing
- ENGS 111: Digital Image Processing
- ENGG 113: Image Visualization and Analysis
- ENGG 122: Image Visualization and Analysis

Nano/microelectronics

- ENGS 126: Analog Integrated Circuit Design
- ENGS 129: Biomedical Circuits and Systems
- ENGS 162: Basic Biological Circuit Engineering
- ENGS 262: Advanced Biological Circuit Engineering
- ENGG 324: Microstrip Lines and Circuits

Optics/Electromagnetics

- ENGS 120: Electromagnetic Waves: Analytical and Modeling Approaches
- ENGS 123: Optics
- ENGS 220: Electromagnetic Wave Theory

Additional Courses

Electronic Systems

- ENGS 159: Molecular Sensors & Nanodevices in Biomedical Engineering
- ENGS 169: Intermediate Biomedical Engineering
- ENGS 147: Mechatronics

Signal Processing

- ENGS 124: Networked Multi-Agent Systems
- ENGG 149: Introduction to Systems Identification
- ENGS 145: Modern Control Theory

Nano/microelectronics

- ENGS 131: Science of Solid State Materials
- ENGS 134: Nanotechnology

Data Science

- ENGS 108: Applied Machine Learning
- COSC 174: Machine Learning and Statistical Data Analysis (Credit allowed for only one of COSC 174 or ENGS 108)
- COSC 178: Deep Learning

Mathematics

- ENGS 92: Fourier Transforms and Complex Variables
- ENGS 105: Computational Methods for Partial Differential Equations I Alt W
- ENGS 106: Numerical Linear Algebra
- PHYS 100: Mathematical Methods for Physicists Fall
- PHYS 105: Electromagnetic Theory I Winter
- PHYS 106: Electromagnetic Theory II Spring
- PHYS 110: Methods in Applied Mathematics II

ENERGY ENGINEERING TRACK

Core Courses

- ENGS 171: Industrial Ecology
- ENGS 172: Climate Change and Engineering
- ENGG 173: Energy Utilization
- ENGS 174: Energy Conversion
- ENGS 175: Energy Systems

Additional Courses

- ENGS 91: Numerical Methods in Computation
- ENGG 103: Operations Research
- ENGS 104: Optimization Methods for Engineering Applications
- ENGS 106: Numerical Linear Algebra
- 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
- 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

MATERIALS ENGINEERING TRACK

Core Courses

- ENGS 130: Mechanical Behavior of Materials
- ENGS 131: Science of Solid State Materials
- ENGS 132: Thermodynamics and Kinetics in Condensed Phases
- ENGS 133: Methods of Materials Characterization
- ENGS 134: Nanotechnology
- ENGS 135: Thin Films and Microfabrication Technology
- ENGG 138: Corrosion and Degradation of Materials
- ENGS 165: Biomaterials
- ENGG 230: Fatigue and Fracture

- ENGG 332: Topics in Plastic Flow and Facture of Solids
- ENGG 339: Advanced Electron Microscopy
- ENGG 365: Advanced Biomaterials

Additional Courses

- 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
- CHEM 101.2: Statistical Thermodynamics

MECHANICAL ENGINEERING TRACK

Core Courses

- ENGS 130: Mechanical Behavior of Materials
- 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

Additional Courses

- 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

Master of Science (MS)

engineering.dartmouth.edu/academics/graduate/ms

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

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

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

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

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

ADVISORS

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

MATCHING INTERESTS TO FACULTY

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

ACADEMIC HONOR

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

graduate.dartmouth.edu/academics/graduate-registrar/academic-honor-code

PREREQUISITES

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

RESIDENCY

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

NUMBER OF COURSES

All students entering the program are required to take 6 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.

GRADE STANDARDS

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

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

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

ADVISORS

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

MS COURSE OPTIONS

Applied mathematics (choose at least 1)	ENGS 91 Numerical Methods in Computation	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 at least 3)	Courses in the area of the student's research should be chosen to increase the student's depth of expertise and knowledge. These courses should be chosen in concert with the thesis advisor from the graduate engineering listings.	3 or more courses*
Engineering breadth (choose at least 2)	The remainder of the courses may be any graduate course listing area, with approval of the thesis advisor and the graduate program committee.	2 or more courses*
	Research leading to a written thesis	
	An oral defense of the thesis	

* Engineering Management courses are not permitted.

MS THESIS REQUIREMENTS

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

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

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

DUAL DEGREES

BE/MS

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

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

MEM/MS

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

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

MD/MS

engineering.dartmouth.edu/academics/graduate/mdms

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

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

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

MD/MS COURSE OPTIONS

Applied mathematics **(choose 1)**	ENGS 91 Numerical Methods in Computation	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
	Research leading to a written thesis	
	An oral defense of the thesis	

Doctor of Philosophy (PhD)

engineering.dartmouth.edu/academics/graduate/phd

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

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

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

RESEARCH

engineering.dartmouth.edu/research

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

Students may pursue research in any of the following categories.

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

PREREQUISITES

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

ACADEMIC HONOR

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

graduate.dartmouth.edu/services/regulations.html

RESIDENCY

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

NUMBER OF COURSES

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

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

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

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

GRADE STANDARDS

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

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

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

FIRST-YEAR PROGRAM PLAN

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

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

This group helps each student develop a first-year program of study, which the student submits to the Thayer School 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

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

FULL PROGRAM PLAN

During the first term, the faculty help the student develop a full program plan to fulfill the PhD requirements, which the student submits to the Thayer School 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	4 terms
ENGG 197 PhD Professional Workshops	1 term (usually taken in one of the latter years in residence)
ENGG 198 Research-in-Progress Workshop	Annual participation during spring break

ANNUAL PHD ADVISOR MEETING REPORT

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

PHD CANDIDACY YEARS

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

REQUIREMENT	DEFINITION	DEMONSTRATED BY	SEE PAGE
Technical proficiency	Knowledge of the principles and methods of engineering, applied science, and applied mathematics underlying the anticipated thesis research	Coursework and oral qualifying examination	67
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	68
Specialization	Mastery of knowledge in the chosen area of research	Presentation of a thesis proposal AND a program of study	69
Professional competence	Ability to develop resources in chosen area of research	ENGG 197 PhD Professional Workshops	69
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	69

Technical Proficiency: Oral Qualifying Examination

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

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

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

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

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

Technical Breadth

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

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

Specialization: Thesis Proposal

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

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

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

Two weeks before the presentation, candidates must:

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

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

Professional Competence: PhD Professional Workshops

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

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

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

Original Research

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

The research is reviewed through all of the following means:

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

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

DISSERTATION ARCHIVING

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

CAREER DEVELOPMENT

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

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

ENGM 179 Accounting
ENGM 180 Corporate Finance
ENGM 181 Marketing
ENGM 182 Data Analytics
ENGM 183 Operations Management
ENGM 185 Topics in Manufacturing Design and Processes
ENGM 186 Technology Project Management
ENGM 187 Technology Innovation and Entrepreneurship
ENGM 188 Law for Technology and Entrepreneurship
ENGM 190 Platform Design, Management, and Strategy
ENGM 191 Product Design and Development

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

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

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

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

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

More formalized teacher training programs, offered through the Dartmouth Center for the Advancement of Learning, are open to Thayer School PhD candidates. More information at:
www.dartmouth.edu/~dcal

PhD Innovation Program

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

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

Skills development	ENGG 195 Seminar on Science, Technology, and Society	4 terms
	ENGG 197 PhD Professional Workshops (recommended but not required; can be used to write a Small Business Innovation Research [SBIR] proposal)	recom-mended
	ENGG 198 Research in Progress Workshop (annual participation)	annual
Applied mathematics (choose 2)	ENGS 91 Numerical Methods in Computation	2 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	Courses in the area of the student's research, chosen to increase the student's depth of expertise and knowledge. These courses should be selected in concert with the thesis advisor.	4 courses
Innovation elective (choose at least 1)	Any graduate-level technical course in area outside the student's area of core expertise	1 course
	ENGM 179 Accounting	
Innovation coursework	ENGM 180 Corporate Finance	4 courses
	ENGM 187 Technology Innovation and Entrepreneurship (typcially in the second year)	
	ENGM 188 Law for Technology, and Entrepreneurship (or equivalent course)	
	ENGG 321 Introduction to Innovation (typically in the fourth year)	
Internship	ENGG 300 Students will work for a company (possibly their own) in their general Research & Development field(s) of interest. The requirement may be waived for students with substantial prior work experience. Prior to starting the internship, students must see Lori Laventure (135A Cummings) to discuss financial/insurance issues.	

The Innovation track includes all the original research requirements of the PhD. See page 64.

PhD Innovation Program
Training in Surgical Innovation

engineering.dartmouth.edu/academics/graduate/innovation/surgical-training-track/

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

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

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

- biomedical engineering
- surgical translation
- innovation and entrepreneurship

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

CENTER FOR SURGICAL INNOVATION

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

INNOVATION & ENTREPRENEURSHIP

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

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

CROSS-COLLABORATION

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

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

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

TIMELINE / FUNDING / OUTCOMES

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

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

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

Graduates of TSI will:

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

ADMISSIONS

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

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

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

MD/PhD in Biomedical Engineering

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

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

PREREQUISITES

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

ACADEMIC HONOR

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

graduate.dartmouth.edu/services/regulations.html

RESIDENCY

MD/PhD candidates are in residence at Thayer School a minimum of 6 terms, including 2 terms of participation in ENGG 195: Seminar on Science, Technology, and Society and 1 term of ENGG 198: Research-in-Progress Workshop.

NUMBER OF COURSES

The candidate with undergraduate engineering training (BE or BS degree) plus 2 years of

Applied mathematics	2-3 courses
Engineering courses leading to a depth of knowledge in an engineering specialty	4 courses

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

ENGG 195 Seminar on Science, Technology and Society	2 terms
ENGG 197 PhD Professional Workshops	1 term
ENGG 198 Research-in-Progress Workshop	1 term

COURSE OF STUDY

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

DEGREE REQUIREMENTS

MD Requirements

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

PhD Requirements

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

Graduate Admissions

engineering.dartmouth.edu/academics/admissions/graduate

ADMISSION REQUIREMENTS

MEM Program

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

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

MEng Program

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

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

MS and PhD Programs

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

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

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

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

APPLICATION PROCEDURE

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

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

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

Supporting documents should be sent to:
Graduate Admissions
Thayer School of Engineering
Dartmouth College
14 Engineering Drive
Hanover, NH 03755-8000

engg.admissions@dartmouth.edu

Thayer Application Deadline: January 1 for the following fall term for MS and PhD applicants. MEng applicants are admitted on a rolling basis. MEM applicants apply in "rounds" with January 15 as the first deadline.
engineering.dartmouth.edu/academics/admissions/graduate

JOINT-DEGREE APPLICANTS

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

MEM/MBA applicants must apply to both Thayer School and Tuck School of Business.

Tuition and Expenses

Tuition for the 2020-2021 academic year is $19,265 per term, which covers instruction, use of instructional facilities, and health care service through the College infirmary.

Students without their own hospital insurance must purchase a Dartmouth College hospital insurance policy for approximately $3,891 a year.

The total cost of a year, including tuition, books, room, board, and incidentals, will be approximately $70,000–74,000 for the academic year 2020–2021. Financial aid can significantly lower the yearly cost.

Financial Aid

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

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

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

fafsa.ed.gov

More information is at:

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

FOR BE, MEM, AND MENG STUDENTS

Full-time students are eligible for 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. BE students who accept partial-tuition scholarship awards will be required to serve as a paid hourly teaching assistant if called upon. After the MEM internship or any leave term during the MEM program, the student is expected to contribute a minimum of $3,000 toward tuition.

At the time of application to the BE, MEM, or MEng programs, full-time applicants interested in applying for need-based aid must submit the PROFILE application available at:
profileonline.collegeboard.com

Awards are made annually on an academic year basis. Students planning to enroll in the MEng or MEM program for more than one academic year) have to re-file the PROFILE application..

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

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

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

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

FINANCIAL AID FOR MS AND PHD STUDENTS*

Typically, an MS or PhD student enters Thayer School with full support on either

FINANCIAL AID	TUITION	STIPEND
Research Assistantship for Master's or first-year PhD student	Full tuition	$2,360 per month
Research Assistantship for PhD candidate	Full tuition	$2,460 per month
Research Assistantship for PhD candidate who has passed the oral examination and the presentation of thesis proposal	Full tuition	$2,560 per month

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

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

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

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

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

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

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

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

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

Registration

RESIDENCY

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

CHECK-IN

All students intending to be in residence must check in at the beginning of each term (see Academic Calendar, page 3) through an on-line check-in process. This practice lets the faculty and administration know who is actually in residence for the new term and facilitates contacting students with individual problems.

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

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

COURSE CHANGES

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

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

WITHDRAWAL

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

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

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

REFUND POLICY

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

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

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

UNDERGRADUATE COURSES

Undergraduate Courses by Category 83

Undergraduate Course Descriptions 85

Prerequisite Courses for Engineering Sciences 101

Undergraduate Courses

engineering.dartmouth.edu/academics/courses/undergraduate

AB REQUIREMENTS

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

DISTRIBUTIVE CODES

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

TERM OFFERED

F Fall
W Winter
S Spring
X Summer

CLASS TIMES

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

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

The Dartmouth College Weekly Schedule Diagram is at:
www.dartmouth.edu/reg/docs/class_schedule.pdf

COURSE TIMES

Course times are indicated for 2 years. Not all courses listed are offered each year. Check the Dartmouth Timetable of Class Meetings rather than the ORC to confirm the latest information about course meeting times, instructor, etc.
oracle-www.dartmouth.edu/dart/groucho/timetable.main

CANCELLATION POLICY

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

Undergraduate Courses by Category

COURSES RECOMMENDED FOR NON-MAJORS		
	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 8	Materials in Sports Equipment
	ENGS 9	Everyday Technology
	ENGS 10	The Science and Engineering of Digital Imaging
	ENGS 11	The Way Things Work
	ENGS 12	Design Thinking
	ENGS 13	Virtual Medicine and Cybercare
	ENGS 15	Undergraduate Investigations in Engineering
	ENGS 15.01	Senior Design Challenge 1
	ENGS 15.02	Senior Design Challenge 2
	ENGS 16	Biomedical Engineering for Global Health
	ENGS 17.04	Making Music: The Art, Science, and Symbolism of Muscial Instruments
	ENGS 18	System Dynamics in Policy Design and Analysis
	ENGS 19.01	Future of Energy (Pending Approval)
COURSES FOR MAJORS AND MINORS		
Engineering Sciences 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
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
Introductory Courses	ENGS 52	Introduction to Operations Research
	ENGS 56	Introduction to Biomedical Engineering

continued

Undergraduate Courses by Category continued

COURSES FOR MAJORS AND MINORS		
Upper-Level Courses	ENGS 41	Sustainability and Natural Resource Management
	ENGS 44	Sustainable Design
	ENGS 46	Advanced Hydrology
	ENGS 50	Software Design and Implementation
	ENGS 57	Intermediate Biomedical Engineering
	ENGS 58	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
	ENGS 85.08	Embedded Systems
	ENGS 86	Independent Project
	ENGS 87	Undergraduate Investigations
	ENGS 88	Honors Thesis
	ENGS 89	Engineering Design Methodology and Project Initiation
	ENGS 90	Engineering Design Methodology and Project Completion
	ENGS 91	Numerical Methods in Computation
	ENGS 92	Fourier Transforms and Complex Variables
	ENGS 93	Statistical Methods in Engineering

Undergraduate Course Descriptions

For current information about engineering course offerings and times:
engineering.dartmouth.edu/academics/courses/undergraduate

ENGS 1 Mathematical Concepts in Engineering

This course introduces prospective engineering students to mathematical concepts relevant in engineering while emphasizing the solving of engineering problems rather than mathematical derivations and theory. All topics are driven by engineering applications taken directly from core engineering courses. The course includes hands-on laboratory exercises as well as a thorough introduction to Matlab. Enrollment is limited to 24 students.

No prerequisite
Dist: TAS

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

An introduction to the integrated design of structures and the evolving role of architects and engineers. The course will investigate the idea that design excellence is very often the result of deep collaboration between engineers, architects, and builders and that it is only in relatively recent history that a distinction between these areas of expertise has existed. The historical, social, and architectural impact of structures will be explored and several structures and their designers will be studied in depth. Enrollment is limited to 50 students.

No prerequisite
Dist: TAS

ENGS 3 Materials: The Substance of Civilization

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

No prerequisite
Dist: TAS

ENGS 4 Technology of Cyberspace

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

ENGS 5 Healthcare and Biotechnology in the 21st Century

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

No prerequisite
Dist: TAS

ENGS 6 Technology and Biosecurity

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

No prerequisite
Dist: TAS

ENGS 7 First-Year Seminars in Engineering

The following courses are available only as part of the First-Year Seminar Program.

ENGS 7.02 Climate Change

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

Dist: TAS

ENGS 7.05 Contemporary and Historical Perspectives on Medical Imaging

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

Dist: TAS

ENGS 7.06 Sustainability Revolution

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

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 30 students.

No prerequisite
Dist: TAS

ENGS 9 Everyday Technology

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

No prerequisite
Dist: TLA

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 prerequisite
Dist: TAS

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

Students will explore and compare engineered solutions to challenges or problems in the world around them. They will sketch and build models to help understand and communicate. After being exposed to some basic engineering principles they will be asked to further investigate specific challenges and possible engineering solutions. What is the problem or need? What are some possible engineered solutions? What are the pros and cons of the different solutions? How could these solutions be improved? They will communicate their findings visually to the class, to the Thayer community, and beyond. Enrollment is limited to 24 students.

No prerequisite
Dist: ART

ENGS 12 Design Thinking

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

No prerequisite
Dist: TAS

ENGS 13 Virtual Medicine and Cybercare

There is a revolution in technology that is occurring in health care. This new technology will dramatically change how health care is delivered in the future. This course will cover topics related to the virtual human created from bits. This will include virtual reality, augmented reality and datafusion, computer simulation, advanced 3D and 4D imaging techniques, the operating room of the future, minimally invasive surgery, space medicine, teleoperations, telemedicine and telesurgery, internet 2 and cyber-space, artificial intelligence and intelligent agents applied to medicine, and the national library of medicine virtual human project. We will also discuss the FDA approval of computer simulators, robotic surgeons, and the ethics of robots doing surgery. In addition we will discuss the medical library of the future, teleconferencing and the use of interactive media in healthcare education. We will also discuss computerized patient records (CPR) and clinical information systems. Enrollment is limited to 48 students.

No prerequisite
Dist: TAS

ENGS 15 Undergraduate Investigations in Engineering

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

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

ENGS 15.01 Senior Design Challenge I

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

No prerequisite
Dist: TAS

ENGS 15.02 Senior Design Challenge II

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

No prerequisite
Dist: TAS

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 prerequisite
Dist: TAS

ENGS 17.04: Making Music: The Art, Science, and Symbolism of Musical Instruments

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 prerequisite
Dist: INT

ENGS 18 System Dynamics in Policy Design and Analysis

This course introduces systems dynamics, an approach to policy design and analysis based upon feedback principles and computer simulation. The approach is useful for gaining an understanding of the underlying structural causes of problem behavior in social, economic, political, environmental, technological, and biological systems. Goals of this approach are to gain better understanding of such problem behaviors and to design policies aimed at improving them. Lectures and exercises illustrate applications of the approach to real, current problems such as urban decay, resource depletion, environmental pollution, product marketing and distribution, and agricultural planning in an expanding population. The similarity and transferability of underlying feedback characteristics among various applications is emphasized. No prior engineering or computer science experience is necessary. Enrollment is limited to 30 students.

Prerequisite: MATH 3
Dist: TAS

ENGS 19.01 Future of Energy

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 prerequisite
Dist: TAS

ENGS 20 Introduction to Scientific Computing

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

This course introduces concepts and techniques for creating computational solutions to problems in engineering and science. The essentials of computer programming are developed using the C and Matlab languages, with the goal of enabling the student to use the computer effectively in subsequent courses. Programming topics include problem decomposition, control structures, recursion, arrays and other data structures, file I/O, graphics, and code libraries. Applications will be drawn from numerical solution of ordinary differential equations, root finding, matrix operations, searching and sorting, simulation, and data analysis. Good programming style and computational efficiency are emphasized. Although no previous programming experience is assumed, a significant time commitment is required. Students planning to pursue the engineering sciences major are advised to take ENGS 20. Students considering the computer science major or majors modified with computer science should take COSC 1 and COSC 10.
Enrollment is limited to 50 students.

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

ENGS 21 Introduction to Engineering

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

Prerequisite: MATH 3 or equivalent
Dist: TAS

ENGS 22 Systems

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

Prerequisite: MATH 13, PHYS 14, and ENGS 20
Dist: TLA

ENGS 23 Distributed Systems and Fields

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

Prerequisite: ENGS 22, or equivalent
Dist: TAS

ENGS 24 Science of Materials

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

Prerequisite: PHYS 14 and CHEM 5
Dist: TLA

ENGS 25 Introduction to Thermodynamics

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

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

ENGS 26 Control Theory

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

Prerequisite: ENGS 22
Dist: TAS

ENGS 27 Discrete and Probabilistic Systems

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

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

ENGS 30 Biological Physics
(Identical to PHYS 30)

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

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

ENGS 31 Digital Electronics
(Identical to COSC 56)

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

Prerequisite: ENGS 20 or COSC 1 and COSC 10
Dist: TLA

ENGS 32 Electronics: Introduction to Linear and Digital Circuits
(Identical to PHYS 48)

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

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

ENGS 33 Solid Mechanics

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. Enrollment is limited to 50 students.

Prerequisites: MATH 13 and PHYS 13
Dist: TLA

ENGS 34 Fluid Mechanics

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

Prerequisites: ENGS 23 or equivalent
Dist: TLA

ENGS 35 Biotechnology and Biochemical Engineering
A consideration of the engineering and scientific basis for using cells or their components in engineered systems. Central topics addressed include kinetics and reactor design for enzyme and cellular systems; fundamentals, techniques, and applications of recombinant DNA technology; and bioseparations. Additional lectures will provide an introduction to metabolic modeling as well as special topics. The course is designed to be accessible to students with both engineering and life-science backgrounds. This course has a graduate section, see ENGS 160. Enrollment is limited to 20 students.

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

ENGS 36 Chemical Engineering
This course will expose students to the fundamental principles of chemical engineering and the application of these principles to a broad range of systems. In the first part of the course, aspects of chemical thermodynamics, reaction kinetics, and transport phenomena will be addressed. These principles will then be applied to a variety of systems including industrial, environmental, and biological examples. Enrollment is limited to 50 students.

Prerequisite: ENGS 22, ENGS 25 and CHEM 5
Dist: TAS

ENGS 37 Introduction to Environmental Engineering
A survey of the sources, measurement techniques, and treatment technologies relating to environmental pollution resulting from the activities of humans. The course will be technology-focused, but will also touch on topics related to the implementation of technology in the real world such as public perception, policy and legislation, and choosing between technological alternatives. Technological and other issues will be addressed relating to water pollution, air pollution, solid wastes, and the fate and transport of pollutants in the environment. Consideration of each area will include general background and key concepts, detailed design examples of importance in the area, and case studies/current topics. The course will include guest lectures. Enrollment is limited to 50 students.

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

ENGS 41 Sustainability and Natural Resource Management
Natural resources sustain human productivity. Principles of scientific resource management are established, including mathematical model development based on material balances and decision making based on dynamical and stochastic systems. Three generic categories of resource are analyzed: exhaustible, living, and renewable. In the first category, we emphasize the life-cycle of exploitation including exhaustion, exploration and substitution. In the living category, we explore population dynamics under natural and harvested regimes, for fisheries, fowl and forests. The renewable case of water is treated in terms of quantity and quality. Finally, air quality management is considered through the lens of assimilative capacity. Throughout, the intersection of natural processes and economic incentives is explored with dynamical systems theory, computer simulations, and optimization techniques. Case studies illustrate contemporary management problems and practices.

Prerequisite: MATH 23 or ENGS 22, and ENGS 37
Dist: TAS

ENGS 44 Sustainable Design
An interdisciplinary introduction to the principles of design for sustainability, with emphasis on the built environment. Through lectures, readings, discussions, and a major design project, students will learn to design buildings and other infrastructure with low to no impact on the environment. Emphasis is on creative thinking, strategies for managing the complexity of the product life-cycle of the infrastructure, and the thorough integration of human and economic aspects in the design. Homework and project activities provide practice in relevant engineering analyses. Enrollment is limited to 25 students.

Prerequisite: ENGS 21 and ENGS 22 or SART 65
Dist: TAS

ENGS 46 Advanced Hydrology
(Identical to EARS 76)
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)
Techniques for building large, reliable, maintainable, and understandable software systems. Topics include UNIX tools and filters, programming in C, software testing, debugging, and teamwork in software development. Concepts are reinforced through a small number of medium-scale programs and one team programming project.

Prerequisite: COSC 10 or equivalent
Dist: TLA

ENGS 52 Introduction to Operations Research
Basic concepts of optimization are introduced as aids in systematic decision-making in engineering contexts. Deterministic optimization is developed in the form of linear and integer programming and their extensions. Probabilistic models are introduced in terms of Markov chains, queuing and inventory theory, and stochastic simulation. The course emphasizes the application of these methods to the design, planning, and operation of complex industrial and public systems.

Prerequisite: MATH 8 and MATH 22 or equivalent
Dist: TAS

ENGS 56 Introduction to Biomedical Engineering
This course will survey applications of engineering principles to medical diagnosis/treatment of disease, monitoring/measurement of physiological function, and rehabilitation/replacement of body dysfunction. Case studies will be used to highlight how engineering has advanced medical practice and understanding. Examples will be drawn from bioinstrumentation, bioelectricity, biotransport, biomaterials, and biomechanics. While investigations will focus primarily on the engineering aspects of related topics, issues surrounding patient safety, public policy and regulation, animal experimentation, etc. will be discussed as appropriate.
Prerequisite: ENGS 22
Dist: TAS

ENGS 57 Intermediate Biomedical Engineering
The basic biomedical engineering concepts introduced in ENGS 56 will serve as the foundation for exploring technology in a clinical environment. The specific clinical setting to be explored will be the operating room (OR). This course will introduce a variety of surgical procedures and technologies from an engineering perspective. Areas of focus will include patient monitoring, biophysical tissue properties, general surgical

instrumentation, tissue cutting and binding technologies, and optical visualization technologies. In addition, state-of-the-art procedures employing image-guided, minimally invasive, laparoscopic, and robot-assisted surgical technologies will be discussed. The first half of the term will include weekly seminars presented by surgeons describing a particular surgical procedure, the technologies currently used and a surgeon's "wish-list". During the second half of the term, students will undertake a design project aimed at developing a technology that addresses a specific need within the OR. Enrollment is limited to 18 students.

Prerequisite: ENGS 23 and ENGS 56 or equivalent
Dist: TAS

ENGS 58 Introduction to Protein Engineering

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

ENGS 59 Basic Biological Circuit Engineering

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

ENGS 60 Introduction to Solid-State Electronic Devices

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

Prerequisite: ENGS 23
Dist: TLA

ENGS 61 Intermediate Electrical Circuits

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

Prerequisite: ENGS 32
Dist: TLA

ENGS 62 Microprocessors in Engineered Systems
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 finites 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. Enrollment is limited to 30 students.

Prerequisite: ENGS 50
Dist: TLA

ENGS 64 Engineering Electromagnetics
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

ENGS 65 Engineering Software Design
As a successor to ENGS 20, this course covers intermediate topics in programming and software design with an emphasis on engineering applications. Students will learn software design principles and basic data structures. Topics covered will include object-oriented design, user interface design, lists, stacks, queues, binary trees, hash tables, and simulation. Students will learn techniques for developing maintainable, extensible, and understandable software.

Prerequisite: ENGS 20 or COSC 1 and COSC 10
Dist: TAS

ENGS 66 Discrete Mathematics in Computer Science
(Identical to COSC 30)
This course integrates discrete mathematics with algorithms and data structures, using computer science applications to motivate the mathematics. It covers logic and proof techniques, induction, set theory, counting, asymptotics, discrete probability, graphs, and trees. MATH 19 is identical to COSC 30 and may substitute for it in any requirement.

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

ENGS 67 Programming Parallel Systems
(Identical to COSC 63)
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

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

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

ENGS 69 Smartphone Programming

(Identical to COSC 65, COSC 165)
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

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

ENGS 72 Applied Mechanics: Dynamics

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

Prerequisite: ENGS 22
Dist: TAS

ENGS 73 Materials Processing and Selection

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

Prerequisite: ENGS 24 and ENGS 33 or equivalent
Dist: TLA

ENGS 75 Product Design
(Can be used for AB course count and Engineering Sciences major elective, but may not be used to satisfy BE requirements other than design credit.)
A laboratory course on human-centered product design. A series of design projects form the vehicle for exploring creative strategies for optimizing product design for human use. The course focus includes need-finding, concept development, iterative modeling, prototyping and testing. The goal is synthesis of technical requirements with aesthetic and human concerns. Includes presentations by visiting professional designers. Enrollment is limited to 20 students.

Prerequisite: ENGS 21 or ENGS 89
Dist: TAS

ENGS 76 Machine Engineering
An introduction to the analysis and synthesis of mechanical components and systems. Lecture topics focus on design and analysis of mechanical components subject to static and fatigue loading conditions, deformation, and buckling. Power transmission shafting, bearings, and gears will be studied in detail. A survey of design requirements for other components—springs, screws, belts, clutches, brakes, roller chains, and welded and riveted connections—will be provided. The class includes laboratory sessions for developing practical skills in design fabrication. A term project emphasizes the synthesis of a working machine to complete a specified task. The project involves the design or selection of components studied, and includes fabrication and demonstration of the machine. Solid modeling software is used as a design tool. Enrollment is limited to 25 students.

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

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

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

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

Prerequisite: Permission of the department chair

ENGS 85.08: Embedded Systems

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 for this initial offering is limited to 12 students.

Prerequisites: ENGS 20 or COSC 10; and PHYS 14 (may be taken concurrently).

ENGS 86 Independent Project

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

ENGS 87 Undergraduate Investigations

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

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.

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

ENGS 88 Honors Thesis

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

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

Prerequisite: Permission of the chair of the Honors program

ENGS 89 Engineering Design Methodology and Project Initiation

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

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

ENGS 90 Engineering Design Methodology and Project Completion

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

Prerequisite: ENGS 89

ENGS 91 Numerical Methods in Computation

(Identical to COSC 71)
(Can be used to satisfy graduate degree requirements)

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

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

ENGS 92 Fourier Transforms and Complex Variables

(Identical to PHYS 70)
(Can be used to satisfy graduate degree requirements)
Offered: 19F, 20F: 2

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

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

ENGS 93 Statistical Methods in Engineering

(Can be used to satisfy graduate degree requirements)
(Enrollment limited to 42 students per section)

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

Prerequisite: MATH 13 or equivalent
Dist: QDS

Prerequisite Courses for Engineering Sciences

For current information about course offerings for all Dartmouth departments: www.dartmouth.edu/~reg

CHEMISTRY

CHEM 5-6 General Chemistry

An introduction to the fundamental principles of chemistry, including chemical stoichiometry; the properties of gases, liquids, and solids; solutions; chemical equilibria; atomic and molecular structure; an introduction to thermodynamics; reaction kinetics; and a discussion of the chemical properties of selected elements. The laboratory work emphasizes physical-chemical measurements, quantitative analysis, and synthesis. An outline of topics for review of secondary school background in preparation for college general chemistry is available from the Department of Chemistry.

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

CHEM 10 Honors First-Year General Chemistry

CHEM 10 is a general chemistry course for students who have a strong background in chemistry and mathematics and who may have an interest in majoring in the sciences. The course will cover selected general chemistry topics important for higher-level chemistry courses. These include thermodynamics, reaction kinetics, quantum mechanics, and bonding. Laboratory work will emphasize physico-chemical measurements and quantitative analysis. CHEM 10 is open only to first-year students and enrollment is limited. Admission is by satisfactory performance on a general chemistry proficiency test given during Orientation. Adequate mathematics preparation, equivalent to MATH 3, is also required. CHEM 10 is offered in the fall term and is the prerequisite equivalent to CHEM 5/6. Students who successfully complete CHEM 10 will also be granted credit for CHEM 5, if they have not already been granted such credit.

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

Supplemental course fee required
Dist: SLA

COMPUTER SCIENCE

COSC 1 Introduction to Programming and Computation

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

COSC 10 Problem Solving via Object-Oriented Programming

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

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

MATHEMATICS

MATH 3 Introduction to Calculus

This course is the basic introduction to calculus. Students planning to specialize in mathematics, computer science, chemistry, physics, or engineering should elect this course in the fall term. Others may elect it in the winter. A study of polynomials and rational functions leads to the introduction of the basic ideas of differential and integral calculus. The course also introduces exponential, logarithmic, and trigonometric functions. The emphasis throughout is on fundamental ideas and problem solving. MATH 3 is open to all students who have had intermediate algebra and plane geometry. No knowledge of trigonometry is required. The lectures are supplemented by problem sessions.
Dist: QDS

MATH 8 Calculus of Functions of One and Several Variables

This course is a sequel to MATH 3 and is appropriate for students who have successfully completed an AB calculus curriculum in secondary school. Roughly half of the course is devoted to topics in one-variable calculus: techniques of integrations, areas, volumes, trigonometric integrals and substitutions, numerical integration, sequences, and series including Taylor series. The second half of the course generally studies scalar valued functions of several variables. It begins with the study of vector geometry, equations of lines and planes, and space curves (velocity, acceleration, arclength). The rest of the course is devoted to studying different calculus of functions of several variables. Topics include limits and continuity, partial derivatives, tangent planes and differentials, the Chain Rule, directional derivatives and applications, and optimization problems including the use of Lagrange multipliers.

Prerequisite: MATH 3 or equivalent
Dist: QDS

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

This course can be viewed as equivalent to MATH 13, but is designed especially for first-year students who have successfully completed a BC calculus curriculum in secondary school. In particular, as part of its syllabus it includes most of the multivariable calculus material present in MATH 8. Topics include vector geometry, equations of lines and planes, and space curves (velocity, acceleration, arclength), limits and continuity, partial derivatives, tangent planes and differentials, the Chain Rule, directional derivatives and applications, and optimization problems. It continues with multiple integration, vector fields, line integrals, and finishes with a study of Green's and Stokes' theorem.
Dist: QDS

MATH 13 Calculus of Vector-Valued Functions

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

Prerequisite: MATH 8 or equivalent.

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

MATH 22 Linear Algebra with Applications

This course presents the fundamental concepts and applications of linear algebra with emphasis on Euclidean space. Significant goals of the course are that the student develop the ability to perform meaningful computations and to write accurate proofs. Topics include bases, subspaces, dimension, determinants, characteristic polynomials, eigenvalues, eigenvectors, and especially matrix representations of linear transformations and change of basis. Applications may be drawn from areas such as optimization, statistics, biology, physics, and signal processing. Students who plan to take either Mathematics 63 or Mathematics 71 are strongly encouraged to take Mathematics 24.

Prerequisite: MATH 8
Dist: QDS

MATH 23 Differential Equations

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

Prerequisite: MATH 13
Dist: QDS

PHYSICS

PHYS 13 Introductory Physics I

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

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

PHYS 14 Introductory Physics II

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

Prerequisites: PHYS 13 and MATH 8
Dist: SLA

GRADUATE COURSES

Graduate Courses by Topic 106

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Management Courses
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Graduate Courses

engineering.dartmouth.edu/academics/courses/graduate

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

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

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

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

COURSE NUMBERS

100-199 Courses with engineering prerequisites numbered below 100
200-299 Courses with engineering prerequisites numbered below 200
300-399 Courses with engineering prerequisites numbered below 300

TERM OFFERED

F Fall
W Winter
S Spring
X Summer

CLASS TIMES

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

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

The Dartmouth College Weekly Schedule Diagram is at:
www.dartmouth.edu/reg/docs/class_schedule.pdf

COURSE TIMES

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

CANCELLATION POLICY

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

Graduate Courses by Topic

Applied Mathematics	ENGS 91	Numerical Methods in Computation
	ENGS 92	Fourier Transforms and Complex Variables
	ENGS 93	Statistical Methods in Engineering
	ENGS 100	Methods in Applied Mathematics I
	ENGG 103	Operations Research
	ENGG 104	Optimization Methods for Engineering Applications
	ENGS 105	Computational Methods for Partial Differential Equations I
	ENGS 106	Numerical Linear Algebra
	ENGS 107	Bayesian Statistical Modeling and Computation
	ENGS 108	Applied Machine Learning
	ENGS 200	Methods in Applied Mathematics II
	ENGS 202	Nonlinear Systems
	ENGS 205	Computational Methods for Partial Differential Equations II
	ENGG 309	Topics in Computational Science
Biological & Chemical Engineering	ENGS 157	Chemical Process Design
	ENGS 158	Chemical Kinetics and Reactors
	ENGS 160	Biotechnology and Biochemical Engineering
	ENGS 161	Metabolic Engineering
	ENGS 162	Basic Biological Circuit Engineering
	ENGS 163	Advanced Protein Engineering
	ENGS 260	Advances in Biotechnology
	ENGS 261	Biomass Energy Systems
	ENGS 262	Advanced Biological Circuit Engineering
Biomedical Engineering	ENGS 159	Molecular Sensors and Nanodevices Biomedical Engineering
	ENGS 164	Medical Diagnostics and Monitoring
	ENGS 165	Biomaterials
	ENGG 166	Quantitative Human Physiology
	ENGS 167	Medical Imaging
	ENGG 168	Biomedical Radiation Transport
	ENGS 169	Intermediate Biomedical Engineering
	ENGS 170	Neuroengineering
	ENGG 365	Advanced Biomaterials
	ENGG 367	Heat Transfer in Hyperthermia Design for Manufacturing
Electrical & Computer Engineering (continued)	ENGS 110	Signal Processing
	ENGS 111	Digital Image Processing
	ENGS 112	Modern Information Technologies
	ENGS 114	Networked Multi-Agent Systems
	ENGS 115	Parallel Computing
	ENGS 116	Computer Engineering: Computer Architecture
	ENGS 120	Electromagnetic Waves: Analytical and Modeling Approaches
	ENGG 122	Advanced Topics in Semiconductor Devices
	ENGS 123	Optics

continued

Graduate Courses by Topic **continued**

Electrical & Computer Engineering	ENGS 124	Optical Devices and Systems
	ENGS 125	Power Electronics and Electromechanical Energy Conversion
	ENGS 126	Analog Integrated Circuit Design
	ENGS 128	Advanced Digital System Design
	ENGS 129	Biomedical Circuits and Systems
	ENGG 210	Spectral Analysis
	ENGG 212	Communications Theory
	ENGS 220	Electromagnetic Wave Theory
	ENGG 310	Advanced Topics in Signals and Systems
	ENGG 312	Topics in Statistical Communication Theory
	ENGG 317	Topics in Digital Computer Design
	ENGG 324	Microstrip Lines and Circuits
Energy Engineering	ENGS 155	Intermediate Thermodynamics
	ENGS 156	Heat, Mass, and Momentum Transfer
	ENGS 171	Industrial Ecology
	ENGS 172	Climate Change and Engineering
	ENGG 173	Energy Utilization
	ENGS 174	Energy Conversion
	ENGS 175	Energy Systems
Engineering Management	ENGG 176	Design for Manufacturing
	ENGG 177	Decision-Making Under Risk and Uncertainty
	ENGM 178	Technology Assessment
	ENGM 179.1	Organizational Behavior
	ENGM 179.2	Strategy
	ENGM 180.1	Accounting
	ENGM 180.2	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 Leadership
	ENGM 188	Law for Technology and Entrepreneurship
	ENGM 189.01	Medical Device Development (.5 credit)
	ENGM 189.02	Medical Device Commercialization (.5 credit)
	ENGM 190	Platform Design, Management, and Strategy
	ENGM 191	Product Design and Development
	ENGM 387	MEM Professional Skills
	ENGG 390	MEM Project

continued

Graduate Courses by Topic continued

Materials Science Engineering	ENGS 130	Mechanical Behavior of Materials
	ENGS 131	Science of Solid State Materials
	ENGS 132	Thermodynamics and Kinetics in Condensed Phases
	ENGS 133	Methods of Materials Characterization
	ENGS 134	Nanotechnology
	ENGS 135	Thin Films and Microfabrication Technology
	ENGG 138	Corrosion and Degradation of Materials
	ENGG 230	Fatigue and Fracture
	ENGG 332	Topics in Plastic Flow and Fracture of Solids
	ENGG 339	Advanced Electron Microscopy
Mechanical & Systems Engineering	ENGS 142	Intermediate Solid Mechanics
	ENGS 145	Modern Control Theory
	ENGS 146	Computer-Aided Mechanical Engineering Design
	ENGS 147	Mechatronics
	ENGG 148	Structural Mechanics
	ENGG 149	Introduction to Systems Identification
	ENGS 150	Intermediate Fluid Mechanics
	ENGS 151	Environmental Fluid Mechanics
	ENGS 152	Magnetohydrodynamics
	ENGS 153	Computational Plasma Dynamics
	ENGS 154	Aircraft Design
	ENGG 240	Kinematics and Dynamics of Machinery
	ENGS 250	Turbulence in Fluids
MS & PhD Research Courses	ENGG 296	Graduate Research (1 credit)
	ENGG 297	Graduate Research (2 credits)
	ENGG 298	Graduate Research (3 credits)
	ENGG 700	Responsible and Ethical Conduct of Research
Independent Study, Seminars & New Courses	ENGG 192	Independent or Group Study in Engineering Sciences
	ENGG 194	PhD Oral Qualifier
	ENGG 195	Seminar on Science, Technology, and Society
	ENGG 197	PhD Professional Workshops
	ENGG 198	Research-In-Progress Workshops
	ENGG 199	Special Topics in Engineering Sciences
	ENGG 199.00	High-Frequency Power Magnetics Design
	ENGG 199.01	Advanced Electrochemical Energy Materials
	ENGG 199.01	Biomechanics
	ENGG 199.03	Model Based Systems Engineering
	ENGG 199.04	Advanced Imaging
	ENGG 295	Supervised Undergraduate Teaching
	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

For current information about engineering course offerings and times:
engineering.dartmouth.edu/academics/courses/graduate

ENGS 91 Numerical Methods in Computation
(Identical to COSC 71)
A study and analysis of important numerical and computational methods for solving engineering and scientific problems. The course will include methods for solving linear and nonlinear equations, doing polynomial interpolation, evaluating integrals, solving ordinary differential equations, and determining eigenvalues and eigenvectors of matrices. The student will be required to write and run computer programs.

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

ENGS 92 Fourier Transforms and Complex Variables
(Identical to PHYS 70)
Survey of a number of mathematical methods of importance in Engineering and Physics with particular emphasis on the Fourier transform as a tool for modeling and analysis. Orthogonal function expansions, Fourier series, discrete and continuous Fourier transforms, generalized functions and sampling theory, complex functions and complex integration, Laplace, Z, and Hilbert transforms. Computational Fourier analysis. Applications to linear systems, waves, and signal processing.

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

ENGS 93 Statistical Methods in Engineering
The application of statistical techniques and concepts to maximize the amount and quality of information resulting from experiments. After a brief introductory summary of fundamental concepts in probability and statistics, topics considered will include probability distributions, sampling distributions, estimation and confidence intervals for parameters of statistical distributions, hypothesis testing, design and analysis of variance for single and multiple-factor experiments, regression analysis, estimation and confidence intervals for parameters of non-statistical models, and statistical quality control.

Prerequisite: MATH 13 or equivalent
Dist: QDS

ENGS 100 Methods in Applied Mathematics I
(Students are encouraged to enroll in PHYS 100 Mathematical Methods for Physicists – Offered 19F: 11)
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

ENGG 103 Operations Research
This course provides an overview of a broad range of deterministic and probabilistic operations research models with a focus on engineering applications. Emphasis is on developing strong formulations, understanding key solution concepts, developing efficient algorithms, and grasping the advantages and limitations of each approach. After a brief overview of linear and discrete optimization models, the course covers four main types of

techniques: network models, queuing theory, discrete events simulation and game theoretic analysis. Various network models and the corresponding solution algorithms are discussed. Key results and applications of queuing models are presented. Uncertainty associated with real-world modeling is captured through simulation techniques with specific emphasis on discrete events simulation. Equilibrium modeling concepts for strategic form games and extensive form games are introduced as extensions of the core optimization concepts. Application examples are drawn from aerospace, biomedical, civil, computer, electrical, industrial, mechanical, and systems engineering.

Prerequisite: ENGS 93 or equivalent

ENGS 104 Optimization Methods for Engineering Applications

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

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

ENGS 105 Computational Methods for Partial Differential Equations

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

ENGS 106 Numerical Linear Algebra

(Identical to COSC 271)

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

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

ENGG 107 Bayesian Statistical Modeling and Computation

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)

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

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

ENGS 110 Signal Processing

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

Prerequisite: ENGS 32 and ENGS 92 or equivalents

ENGS 111 Digital Image Processing

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

ENGS 112 Modern Information Technologies

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

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

ENGS 114 Networked Multi-Agent Systems

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

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

ENGS 115 Parallel Computing

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

Prerequisite: ENGS 91 (or COSC 71 or equivalent)

ENGS 116 Computer Engineering: Computer Architecture

(Identical to COSC 251)

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

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

ENGS 120 Electromagnetic Waves: Analytical and Modeling Approaches

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

Prerequisite: ENGS 64 or equivalent

ENGG 122 Advanced Topics in Semiconductor Devices

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

Prerequisite: ENGS 60 or equivalent

ENGS 123 Optics

(Identical to PHYS 123)

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

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

ENGS 124 Optical Devices and Systems

(Identical to PHYS 124)

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

Prerequisite: ENGS 23

ENGS 125 Power Electronics and Electromechanical Energy Conversion

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

Prerequisite: ENGS 23 and ENGS 32

ENGS 126 Analog Integrated Circuit Design

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

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

ENGS 128 Advanced Digital System Design

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

Prerequisite: ENGS 31 and ENGS 62 or COSC 51

ENGS 129 Biomedical Circuits and Systems

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

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

ENGS 130 Mechanical Behavior of Materials

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

Prerequisite: ENGS 24 and ENGS 33, or equivalent

ENGS 131 Science of Solid State Materials

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

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

ENGS 132 Thermodynamics and Kinetics in Condensed Phases

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.

Prerequisite: ENGS 24 and ENGS 25, or equivalent

ENGS 133 Methods of Materials Characterization

(Identical to PHYS 128 and CHEM 137)

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

ENGS 134 Nanotechnology

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

ENGS 135 Thin Films and Microfabrication Technology

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

ENGG 138 Corrosion and Degradation of Materials

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

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

Prerequisites: ENGS 24 and CHEM 5

ENGS 142 Intermediate Solid Mechanics

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

Prerequisite: ENGS 71 or ENGS 76 or equivalent

ENGS 145 Modern Control Theory

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

Prerequisite: ENGS 26

ENGS 146 Computer-Aided Mechanical Engineering Design

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

ENGS 147 Mechatronics

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

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

ENGG 148 Structural Mechanics

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

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

Prerequisite: ENGS 33

ENGG 149 Introduction to Systems Identification
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

ENGS 150 Intermediate Fluid Mechanics
Following a review of the basis equations of fluid mechanics, the subjects of potential flow, viscous flows, boundary layer theory, turbulence, compressible flow, and wave propagation are considered at the intermediate level. The course provides a basis for subsequent more specialized studies at an advanced level.

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

ENGS 151 Environmental Fluid Mechanics
Applications of fluid mechanics to natural flows of water and air in environmentally relevant systems. The course begins with a review of fundamental fluid physics with emphasis on mass, momentum and energy conservation. These concepts are then utilized to study processes that naturally occur in air and water, such as boundary layers, waves, instabilities, turbulence, mixing, convection, plumes and stratification. The knowledge of these processes is then sequentially applied to the following environmental fluid systems: rivers and streams, wetlands, lakes and reservoirs, estuaries, the coastal ocean, smokestack plumes, urban airsheds, the lower atmospheric boundary layer, and the troposphere. Interactions between air and water systems are also studied in context (for example, sea breeze in the context of the lower atmospheric boundary layer).

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

ENGS 152 Magnetohydrodynamics
(Identical to PHYS 115)
The fluid description of plasmas and electrically conducting fluids including magnetohydrodynamics and two-fluid fluid theory. Applications to laboratory and space plasmas including magnetostatics, stationary flows, waves, instabilities, and shocks.

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

ENGS 153 Computational Plasma Dynamics
(Identical to PHYS 118)
Theory and computational techniques used in contemporary plasma physics, especially nonlinear plasma dynamics, including fluid, particle and hybrid simulation approaches, also linear dispersion codes and data analysis. This is a “hands-on” numerical course; students will run plasma simulation codes and do a significant amount of new programming (using Matlab).

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

ENGS 155 Intermediate Thermodynamics
The concepts of work, heat, and thermodynamic properties are reviewed. Special consideration is given to derivation of entropy through information theory and statistical mechanics. Chemical and phase equilibria are studied and applied to industrial processes. Many thermodynamic processes are analyzed; the concept of exergy (availability) is used to evaluate their performance, and identify ways to improve their efficiency.

Prerequisite: ENGS 25

ENGS 156 Heat, Mass, and Momentum Transfer

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

Prerequisite: ENGS 25, ENGS 34

ENGS 157 Chemical Process Design

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

Prerequisite: ENGS 36

ENGS 158 Chemical Kinetics and Reactors

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

Prerequisite: ENGS 36

ENGS 159 Molecular Sensors and Nanodevices in Biomedical Engineering

Introduction to fundamentals and major types of molecular sensor systems, scaling laws of device miniaturization, and detection mechanisms, including molecular capture mechanisms; electrical, optical, and mechanical transducers; micro-array analysis of biomolecules; semiconductor and metal nanosensors; microfluidic systems; and 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.

Prerequisite: ENGS 22, CHEM 6, or equivalent

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.

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

ENGS 161 Metabolic Engineering

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

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

ENGS 162 Basic Biological Circuit Engineering

This course will provide a comprehensive introduction to the design, modeling, and experimental implementation of synthetic bio-molecular circuits in living cells. Simple but sophisticated synthetic biological circuits will be implemented and tested in microbial cells in the laboratory including those involving molecular amplification, regulatory feedback loops with biological nonlinearities, and robust analog circuits. Computer aided design, modeling, and simulation will use CADENCE, an industry standard electronic circuit design tool showing how to design, model, and fit actual experimental biological data such that engineering circuit theory and biological experiment agree. Not open to students who have taken ENGS 59.

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

ENGS 163 Advanced Protein Engineering
(Not open to AB and BE students. Students in these degree programs are encouraged to enroll in ENGS 58)
This course will build on molecular engineering fundaments introduced in ENGS58 and equip students to formulate novel engineered molecules by translating methods into practical design proposals. The three components of any protein engineering effort will be surveyed: host strain, library design, and selective pressure. Both gold standard and novel engineering methodologies will be studied, and tradeoffs among different techniques will be examined through detailed case studies. Data presentation and interpretation skills will be developed by examining current literature focused on proteins with practical utility.

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

ENGS 165 Biomaterials
Consideration of material problems is perhaps one of the most important aspects of prosthetic implant design. The effects of the implant material on the biological system as well as the effect of the biological environment on the implant must be considered. In this regard, biomaterial problems and the bioelectrical control systems regulating tissue responses to cardiovascular and orthopedic implants will be discussed. Examples of prosthetic devices currently being used and new developments of materials appropriate for future use in implantation will be taken from the literature.

Prerequisite: ENGS 24, or equivalent

ENGG 166 Quantitative Human Physiology
(Can be used by undergraduates for AB course count only)
Introduction to human physiology using the quantitative methods of engineering and physical science. Topical coverage includes cellular membrane ion transport, Hodgkin-Huxley models and action potentials, musculoskeletal system, cardiovascular physiology, respiratory physiology, and nervous system physiology. Laboratory exercises and a final project delve into the measurement of human physiology, data analysis, and model testing.

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

ENGS 167 Medical Imaging
A comprehensive introduction to all major aspects of standard medical imaging systems used today. Topics include radiation, dosimetry, x-ray imaging, computed tomography, nuclear medicine, MRI, ultrasound, and imaging applications in therapy. The fundamental mathematics underlying each imaging modality is reviewed and an engineering picture of the hardware needed to implement each system is examined. The course will incorporate a journal club review of research papers, term tests, and a term project to be completed on an imaging system.

Prerequisite: ENGS 92 (may be taken conconcurrently)

ENGG 168 Biomedical Radiation Transport
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 modelbasedapproaches will be covered as well, such as the Monte Carlo model. Numerical approaches to solving these models will be introduced.

Prerequisite: ENGS 23 or equivalent

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.

Prerequisite: ENGS 23 and ENGS 56 or equivalent

ENGS 170 Neuroengineering

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

Prerequisite: ENGS 22 and ENGS 56

ENGS 171 Industrial Ecology

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.

ENGS 172 Climate Change and Engineering

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

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

ENGG 173 Energy Utilization

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.

Prerequisties: 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.

ENGS 174 Energy Conversion

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.

ENGS 175 Energy Systems

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

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

ENGG 176 Design for Manufacturing

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

Prerequisite: ENGS 73 or permission of instructor

ENGG 177 Decision-Making under Risk and Uncertainty

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

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

ENGM 178 Technology Assessment

(Cannot be used to satisfy any AB degree requirements)

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

No prerequisite

ENGS 179-1 Organizational Behavior

ENGS 179-2 Strategy

ENGM 180-1 Accounting

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

No prerequisite

ENGM 180-2 Corporate Finance

(Cannot be used to satisfy any AB degree requirements)

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

Prerequisite: ENGM 179 or permission of instructor

ENGM 181 Marketing

(Cannot be used to satisfy any AB degree requirements)

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

Prerequisite: Permission of instructor

ENGM 182 Data Analytics

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 usings analytics to solve business problems. Students work with real-world business data and analytics software. Where possible, cases are used to motivate the topic being covered. Students acquire a working knowledge of the “R”language and environment for statistical computing and graphics. Prior experience with “R” is not necessary, but students should have a basic familiarity with statistics, probability, and be comfortable with basic data manipulation in Excel spreadsheets.

Prerequisite: ENGS 93 or equivalent or permission of the instructor

ENGM 183 Operations Management

(Cannot be used to satisfy any AB degree requirements)

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

Prerequisite: ENGS 93

ENGM 184 Introduction to Optimization Methods

(Cannot be used to satisfy any AB degree requirements)

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

No prerequisite

ENGM 185 Topics in Manufacturing Design and Processes

(Cannot be used to satisfy any AB degree requirements)

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

Prerequisite: ENGS 93

ENGM 186 Technology Project Management

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

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

Prerequisite: ENGM 184 or equivalent

ENGM 187 Technology Innovation and Entrepreneurship

(Cannot be used to satisfy any AB degree requirements)

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

No prerequisite

ENGM 188 Law for Technology and Entrepreneurship

(Cannot be used to satisfy any AB degree requirements)

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

No prerequisite

ENGM 189 Topics in Engineering Management

(Cannot be used to satisfy any AB degree requirements)

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

ENGM 189-01 Medical Device Commercialization

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.

Prerequisites: Graduate standing in engineering or business administration.

ENGM 189-02 Medical Device Development

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

Prerequisite: Graduate standing in engineering or business administration

ENGM 190 Platform Design, Management, and Strategy

(Cannot be used to satisfy any AB degree requirements)

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.

No prerequisite

ENGM 191 Product Design and Development

(Cannot be used to satisfy any AB degree requirements)

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, Thayer PhD Innovation, Tuck MBA students, and Dartmouth medical students.

Prerequisite: ENGM 183 or Instructor permission

ENGG 192 Independent or Group Study in Engineering Sciences

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

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

ENGG 194 PhD Oral Qualifier

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

The oral qualifying exam, a set of questions put forward by an oral examination committee to the candidate, normally takes place before or during the fifth term of the student's program, or, in exceptional circumstances, early in the sixth term. The exam is open to the faculty, but not to the general public.The committee tests the candidate's knowledge of principles and methods underlying the field in which advanced work is to be performed. The exam covers material selected by the candidate's advisor in consultation with the examining committee, and includes coverage of mathematical techniques appropriate to the research area. The structure of the preparation for the exam is flexible.

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

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

ENGG 195 Seminar on Science, Technology, and Society

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

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

Prerequisite: Ph.D. student standing

ENGG 197 PhD Professional Workshops

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

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

Prerequisite: PhD student standing

ENGG 198 Research-In-Progress Workshop

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

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

Prerequisite: PhD student standing

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 199-00 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.

ENGG 199-01 Advanced Electrochemical Energy Materials

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)

ENGG 199-01 Biomechanics

The goal of this course is to introduce graduate level and senior undergraduate students who are working in biomedical imaging research to image processing and visualization in 3D using advanced libraries and fully functional software development framework. The two 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) and the Visualization Toolkit (VTK). 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 control to track code changes and bugs, Qt for user interface development, and CMake for development environment control. 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.

ENGG 199-03 Model Based Systems Engineering

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 char- acterized 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.

ENGG 199-04 Advanced Imaging

An examination of new trends in imaging science. An introduction into imaging theory is presented, including wave propagation, image formation, imaging systems, image quality, and noise sources. Then, advanced topics such as super-resolution imaging, compressed sensing, spectroscopic imaging, wavefront shaping, and holography are studied. Material draws heavily from recent literature. The course incorporates programming projects, critical reviews of journal articles, and construction of original review papers.

Prerequisites: ENGS 92 or equivalent (can be taken concurrently).

ENGS 200 Methods in Applied Mathematics II

(Identical to PHYS 110)

Continuation of ENGS 100 with emphasis on variational calculus, integral equations, and asymptotic and perturbation methods for integrals and differential equations. Selected topics include functional differentiation, Hamilton's principle, Rayleigh-Ritz method, Fredholm and Volterra equations, integral transforms, Schmidt-Hilbert theory, asymptotic series, methods of steepest descent and stationary phase, boundary layer theory, WKB methods, and multiple-scale theory.

Prerequisite: ENGS 100, or equivalent

ENGS 202 Nonlinear Systems

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

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

ENGS 205 Computational Methods for Partial Differential Equations II

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.

Prerequisite: ENGS 105
Instructor: Paulsen

ENGG 210 Spectral Analysis

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

Prerequisite: ENGS 110

ENGG 212 Communications Theory

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

Prerequisite: ENGS 110

ENGS 220 Electromagnetic Wave Theory

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

Prerequisite: ENGS 100 and ENGS 120 or permission of the instructor

ENGG 230 Fatigue and Fracture

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

Prerequisite: ENGS 130 or permission of instructor

ENGG 240 Kinematics and Dynamics of Machinery

(Can be used by undergraduates for AB course count only)
A study of kinematics, dynamics, and vibrations of mechanical components. Topics will include kinematic analysis and synthesis of mechanisms, with applications to linkages, cams, gears, etc.; dynamics of reciprocating and rotating machinery; and mechanical vibrations. Computer-aided design and analysis of kinematic and kinetic models.

Prerequisite: ENGS 72

ENGS 250 Turbulence in Fluids

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

Prerequisite: ENGS 150 or equivalent

ENGG 260 Advances in Biotechnology

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

ENGG 261 Biomass Energy Systems

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

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

Prerequisite: ENGS 157 and ENGS 161 and permission of instructor

ENGS 262 Advanced Biological Circuit Engineering

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

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

ENGS 295 Supervised Undergraduate Teaching

Limited to Ph.D. candidates with permission of Thayer Research Advisor and Course Instructor.

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: Normally, students will elect this course in a term subsequent to passing the qualifying examination

ENGG 296 Graduate Research (1 credit)
Offered: all terms: arrange

ENGG 297 Graduate Research (2 credits)
Offered: all terms: arrange

ENGG 298 Graduate Research (3 credits)
Offered: all terms: arrange

ENGG 299 Advanced Special Topics in Engineering Sciences
(Cannot be used to satisfy any AB degree requirements)

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

ENGG 300 Enterprise Experience Project
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.

ENGG 309 Topics in Computational Science

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

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

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

Prerequisites: ENGS 34 and ENGS 105, or equivalent

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

Prerequisites: ENGS 33 and ENGS 105, or equivalent

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

Prerequisites: ENGS 105 and ENGS 120

ENGG 310 Advanced Topics in Signals and Systems

(Cannot be used to satisfy any AB degree requirements)

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

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

ENGG 312 Topics in Statistical Communication Theory

(Cannot be used to satisfy any AB degree requirements)

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

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

ENGG 317 Topics in Digital Computer Design

(Cannot be used to satisfy any AB degree requirements)

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

Prerequisites: ENGS 116 and permission of instructor

ENGG 321 Advanced Innovation and Entrepreneurship

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

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

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

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

ENGG 324 Microstrip Lines and Circuits

(Cannot be used to satisfy any AB degree requirements)

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

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

ENGG 325 Introduction to Surgical Innovation

(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 of three 10-week terms over one academic year (fall/general surgery, winter/surgical elective, and spring/surgical research). Student effort is approximately 20 hours per week (15 hours of activity and 5 hours to prepare assignments, read, think, and write). This unique course provides experiential learning on the life cycle of surgical devices, including: (1) defining a clinical need; (2) consideration of surgical risks and benefits from a patients point of view; (4) steps in the surgical procedure that could benefit from innovation to improve patient outcomes or make the procedure easier to perform; (5) managing surgical implants and instruments from a surgical scrub technologist's point of view; (6) steps in surgical device procurement, processing, packaging, sterilization, and inventory management; (7) post-surgical patient care and device performance surveillance.

The course begins in the *fall term* with a general surgery rotation. Engineering doctoral TSI (Training in Surgical Innovation) students work alongside 3rd year medical students and surgical residents. Each morning they attend the daily conference (e.g., indications, morbidity & mortality, journal club, tumor board, or grand rounds, 3-5h/wk).

TSI students participate in the weekly medical student case discussion (2h) and also the weekly surgical resident simulation bioskills workshop (2h). Each student is assigned a surgeon proctor to help them navigate the clinical environment and understand context. Each week the student observes at least one outpatient clinic patient encounter (1-2h) and one surgical procedure (3-5h) with the proctor or another surgeon colleague arranged through the proctor. The outpatient clinic encounters focus on pre-operative patients to observe surgical consent discussions and post-operative patients to highlight surgical outcomes ascertainment and adverse event surveillance.

On the day of surgery, the student arrives early to meet the surgical scrub technologist and help prepare for the surgery. The student then meets the patient preoperatively with the proctor and observes the surgical procedure from start to finish. The student follows the surgical scrub tech post-operatively to see instrument processing through central supply processing, sterilization and inventory management. Each week the student produces a 1-page write-up identifying opportunities for innovation to improve patient outcomes or easy of performance for the observed surgical procedure. The write-ups are evaluated and scored by Drs. Paulsen and Mirza.

The *winter term* has a similar schedule with a different proctor (and set of surgeon colleagues) from a surgical subspecialty of the student's choice, such as minimally invasive general surgery, oncologic surgery, otolaryngology, anesthesiology, neurosurgery or orthopedic surgery.

The *spring term* is a research rotation in which students select a clinical mentor and an engineering mentor to guide development of a research proposal. The rotation focuses on medical research methods, including design of clinical trials, evaluation of benefits and harms, and standards for surgical materials/device performance and implant bioeffects. The rotation emphasizes clinical trial design and data analysis from a regulatory perspective.

Activities include engaging clinicians, engineers, other scientists, and the medical device industry to understand relevant FDA regulations and legislation, roles and responsibilities of federal advisory committees, types of applications (PMA/IDE/510k), review and consult processes, and role of device companies. Participants learn about the steps required to develop, protect, and finance an idea as a "laboratory" exercise and work to implement a specific idea (project), culminating in the development of a draft IP position and business plan. The focus of the training experience is on innovation and creation of new technology-driven start-up companies (not on business management).

The final written assignment for the Surgical Innovation Course is a 6-page research proposal for development and validation of a novel surgical technology, similar in format to an NIH Small Business Innovation Research (SBIR) grant. The student also attends at least one hospital surgical implant purchasing committee meeting during the term and writes a one-page report on the device procurement decision-making process. Both the purchasing process write-up and research proposal are evaluated and scored by the student's mentors and also by Drs. Paulsen and Mirza.

Prerequisites: permission of instructor(s)

ENGG 332 Topics in Plastic Flow and Fracture of Solids

(Cannot be used to satisfy any AB degree requirements)

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

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

ENGG 339 Advanced Electron Microscopy

(Cannot be used to satisfy any AB degree requirements)

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

Prerequisite: ENGS 133 or permission of instructor

ENGG 365 Advanced Biomaterials

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

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

Prerequisites: ENGS 165 and permission of instructor

ENGG 367 Heat Transfer in Hyperthermia

(Cannot be used to satisfy any AB requirements)

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

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

ENGM 387 MEM Professional Skills

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

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

No prerequisite

ENGG 390 MEM Project

Offered: all terms

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

Prerequisites: ENGM 178 or permission of instructor

ENGG 700 Responsible and Ethical Conduct of Research

For new MS & PhD students only.

Management Courses (Tuck School of Business)

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

tuck.dartmouth.edu/mba/elective-curriculum/elective-courses

Advanced Competitive Strategy

The Business of Healthcare

Data Mining for Business Analytics

Consulting Project Management

Corporate Communications

Energy Economics

Global Strategy & Implementation

Leadership Out of the Box

Marketing Research

Negotiations

Operations Strategy

Services Operations

Strategic Brand Management

Notice of Nondiscrimination

Dartmouth is dedicated to establishing and maintaining a safe and nondiscriminatory learning, living, and working environment in which all individuals are treated with respect and dignity. The College's Principle of Community establishes that interactions between and among members of the Dartmouth community should be based on integrity, responsibility, and consideration so that all may fully access and benefit from the opportunities the College provides.

Dartmouth is committed to the principle of equal opportunity for all its students, faculty, staff, and applicants for admission and employment. For that reason, Dartmouth prohibits any form of discrimination against any person on the basis of race, color, religion, sex, gender identity or expression, pregnancy, age, sexual orientation, marital or parental status, national origin, citizenship, disability, genetic information, military or veteran status, or any other legally protected status in the administration of and access to the College's programs and activities, and in conditions of admission and employment. Dartmouth adheres to all applicable state and federal equal opportunity laws and regulations.

Inquiries or complaints concerning the application of Title IX of the Education Amendments of 1972, including the institutional response to sex discrimination and sexual and gender-based harassment, may be referred to the Title IX Coordinator and/or the United States Department of Education:

Kristi Clemens
Title IX Coordinator & Clery Act Compliance Officer

Parkhurst Hall, Room 005
Hanover, NH 03755-3541
Phone: 603-646-0922
Email: titleix@dartmouth.edu

Office for Civil Rights, Region I: Boston Office
United States Department of Education
5 Post Office Square, 8th Floor
Boston, MA 02109-3921
Phone: 617-289-0111 | Fax: 617-289-0150
TDD: 800-368-1019
Email: ocr.boston@ed.gov

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:

Office of Institutional Diversity & Equity
Parkhurst Hall, Room 006
Hanover, NH 03755-3541
Phone: 603-646-1606 | Fax: 603-646-2516
Email: institutional.diversity.&.equity@dartmouth.edu
Web: Dartmouth.edu/~IDE

United States Equal Employment Opportunity Commission
Boston Office

John F. Kennedy Federal Building
475 Government Center
Boston, MA 02203

Phone: 800.669.4000 | Fax: 617.565.3196
TDD: 800.669.6820
Web: eeoc.gov/field/boston/index.cfm

New Hampshire Commission for Human Rights
2 Industrial Park Drive
Concord, NH 03301

Phone: 603-271-2767 | Fax: 603-271-6339
E-mail: humanrights@nhsa.state.nh.us
Web: nh.gov/hrc/