The Dartmouth College Bachelor of Arts in Engineering Sciences

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Abstract

The Thayer School of Engineering at Dartmouth College was founded in 1867 with the goal of producing engineers educated in the liberal arts as well as thoroughly trained in technical subjects. Since the mid-1960s, the implementation of the founding vision has been in the form of an interdisciplinary Bachelor of Arts (A.B.) program in Engineering Sciences, followed by a fifth year of further study leading to the Bachelor of Engineering (B.E.) degree. The A.B. program is extraordinarily flexible. About half of the courses taken are in mathematics, natural sciences, and engineering sciences; the remainder is devoted to liberal arts and free electives. The major proper consists of an interdisciplinary core in design and systems analysis, and introductions to particular engineering disciplines. About a third of our undergraduates "modify" the major with another science, with economics, or with studio art, tuning the program to their professional interests. The program's flexibility also facilitates student participation in the full spectrum of extracurricular activities, including study abroad programs, varsity athletics, and performing arts, and many complete minors or second majors. On the other hand, students with a modest amount of advanced placement credit can use their free electives to accelerate completion of the B.E.; about twenty percent complete both degrees in four years. The Engineering Sciences major is among the most popular at Dartmouth: on average, about 65 students graduate each year, of which nearly a quarter are female. Most graduates complete the ABET-accredited B.E. program, but a considerable number go from the A.B. to graduate studies in business, medicine, and law as well as engineering. We also offer two minors and over a dozen technology literacy courses for nonmajors. This paper describes the philosophy, implementation, and student outcomes of the Dartmouth A.B. program in Engineering Sciences.

INTRODUCTION

The economic prosperity of the Western world, driven by science and engineering, is one of the great success stories of the latter half of the twentieth century. Now, at the beginning of the twenty-first, the same technology-fueled growth is spreading to other nations, particularly in Asia. With this comes a concern about the continued competitiveness of the Western (and closest to home, the American) technological engine, and its scientific and engineering underpinnings. Moreover, worries are expressed in some circles that the culture as a whole is not keeping up with the rapid pace of technological change. Will educated people, not just engineers, be ready for a world in which the stuff of everyday life—business, health care, and entertainment, to name a few—is driven by technology? And will engineers be able, more than ever before, to grasp the social and global impacts of technology?

These concerns are reflected, for example, in the recent NAE report "Educating the Engineer of 2020" [1]. The writers make fourteen recommendations for "reengineering" engineering education that reach beyond the purely technical preparation of engineers. Among these are

- a " 'liberal' engineering education… as a springboard for other career pursuits."
- early exposure to design, especially teamwork and social relevance
- interdisciplinary undergraduate engineering education
- encouraging continuous learning
- promoting the engineering and technological literacy of the public

Some of these objectives are recognizable as the familiar virtues of the traditional liberal arts education: disciplinary breadth, continuous learning, and preparation for a wide variety of careers. Yet within the traditional structure of an engineering program, breadth—at the level associated with a liberal arts education— has been virtually unthinkable.

The Bachelor of Arts in engineering is one solution for students who seek some technological fluency, with their eyes set on a career path outside engineering [2]. The engineering requirements are fewer and broader than in a B.S. program, allowing more courses to be selected from the liberal arts. Most such programs are of recent origin, and are still finding their place in the overall curriculum. Usually, but not always, the B.A. is defined as a separate path from the B.S; students choose one or the other.

For over four decades, the Bachelor of Arts (A.B.) in engineering sciences has been the foundation for engineering education at Dartmouth College. Students fulfill the same liberal arts requirements as all other Dartmouth students. The major proper features an interdisciplinary approach to engineering sciences and numerous team design experiences. The A.B. program serves equally well as preparation for further engineering education—at Thayer School and elsewhere—and for other professions. This paper describes the history and philosophy of the Dartmouth program, its current implementation, and its outcomes.

HISTORY

In 1867 General Sylvanus Thayer, retired Superintendent of the U.S. Military Academy, donated the then substantial sum of forty thousand dollars to his alma mater, Dartmouth College, "for the purpose of establishing and sustaining, in connection with that Institution, a School or Department of Architecture and Civil Engineering…" [3, p. xii]. The school opened in 1871, and by 1879 the pattern of engineering training founded on a liberal education was established. From the course announcement of that year:

> …But all persons having Civil Engineering in view, are strongly urged to take a full collegiate course, preferably on a classical but alternatively on a scientific basis, by which, in addition to the knowledge of the special preparatory subjects above named, may be acquired a broader and more liberal training which, as in other professions, so in Civil Engineering, constitutes a preparation of the highest value.

> To this principle the careers of illustrious engineers bear testimony; and if true in the past, much more will it be emphasized by the severer demands of the future. [3, p. 49]

Through the first half of the twentieth century Thayer was largely a civil engineering school. Electrical and mechanical engineering were added in 1941. The curriculum followed a 3-2 model, three years in Dartmouth College followed by two in the Thayer School. This changed with the upheaval in American engineering education that occurred during the 1950s (captured, for example, in the famous Grinter Report [4]). In 1958 the separate departments of civil, electrical, and mechanical engineering were merged into a single department of Engineering Sciences within Dartmouth College, and the degree program changed from 3-2 to 4-1: students entered the Thayer School's professional Bachelor of Engineering (B.E.) program after completing the Bachelor of Arts (A.B.) in engineering sciences. The revolution continued in the early 1960s. Under the leadership of Dean Myron Tribus, a group of young faculty implemented an interdisciplinary core of engineering science courses: a design-oriented introduction to engineering; lumped-parameter systems; distributed-parameter systems and fields; thermodynamics; solid mechanics; and materials science. This bore some resemblance to the Grinter Report's recommendations for a core curriculum (solid mechanics, fluid mechanics, thermodynamics, transport and rate mechanisms, electrical theory, and materials science) [4], but placed a greater emphasis on cross-disciplinary connections. The introduction to engineering course gave students an early exposure to solving real problems of societal importance, imparting a design process for carrying an idea from concept to prototype. The two-course sequence in systems stressed common methods of problem formulation and solution across multiple disciplines.

The "breadth before depth" principle embodied in the core curriculum was a sort of "liberal arts of engineering", and hearkened back to ideas articulated by Thayer School's first dean, Robert Fletcher, in 1909:

> It is certain that many, heretofore, have turned to a specialty with undue haste, and have found later that it was a mistaken choice, and that they have narrowed their future possibilities; it is also certain that men with the large and more thorough all-around training have been able to adjust themselves to a wider range of emergency and opportunity; while there is force in the argument that in the broader curriculum it is difficult to treat the separate subjects with the necessary thoroughness, it is found in practice that one well trained in the fundamentals seldom fails to fit himself (given a little time) to a special responsibility. [3, p. 101]

With minor variations, this core curriculum was the common experience for two decades of engineering science students. In the 1980s, however, it was recognized that the world of engineering had expanded; disciplines like computer, environmental, and bio-engineering that were at most embryonic in the early 1960s, were coming to prominence. The core needed updating. In response, another major revision of the curriculum occurred in the early 1990s, producing the program we offer today.

PROGRAM STRUCTURE

Every academic program evolves within a particular institutional environment, and the present program is no exception. The academic calendar at Dartmouth College is divided into four ten-week terms. Students typically take three courses per term; thirty-five are required for graduation. The summer term is required for students completing their sophomore year; they take a compensating off term during the fall, winter, or spring of the sophomore or junior year. All

Dartmouth students are admitted through a common process; there are no separate admissions into engineering. Students are required to declare their majors no later than the end of the sophomore year. Typically, a prospective engineering sciences major will have taken all of the prerequisites and two or more courses in the major proper by the time he or she formally declares. Retention of declared majors is high. Currently we have about 65 students per graduating class, making us the second most popular science major (after biology) and the seventh most popular major overall in the college. One quarter of the students are female. In addition, the Thayer School graduates about one hundred post-A.B. students—B.E., M.S., M.E.M. (Master of Engineering Management), and Ph.D.—per year.

The A.B. in engineering sciences has four components: liberal arts distributives, math and science prerequisites, core and elective engineering science courses, and free electives.

Liberal Arts

Engineering sciences students fulfill the same general education requirements as all other Dartmouth students. These include courses in writing and foreign language, as well as humanities, natural and social sciences. The median number of non-science courses taken by engineering students in the most recent graduating class was twelve, and none took fewer than nine; that is, the typical engineering sciences student takes one third of his or her courses in the humanities and social sciences. The foreign language requirement carries with it the opportunity for foreign study, which engineering students elect at only a slightly lower rate than Dartmouth students in general. With rare exceptions, engineering students take the same study abroad programs as other students, focusing on language and culture, not on engineering.

Mathematics and science

The prerequisites for the major are calculus through multivariable (3 courses); physics (2); chemistry (1); computer science (1). Modified majors (described later) have additional prerequisites. The mathematics and physics are typically taken in the first year. Computer science is frequently taken in the spring of the first year, and chemistry in the second year.

Engineering sciences

Creative design and a unified approach to systems thinking are the foundation of our educational philosophy. For this reason, the major retains a required core of three courses: the design-oriented introduction to engineering and the two interdisciplinary systems courses. The introduction to engineering is typically taken in the spring of the first year or fall of the sophomore year, providing an early immersion in design and problem solving. Student teams are given a general theme and assigned the task of developing a practical device that meets a real-world need. The course is simultaneously structured in its approach to problem solving and open-ended in the freedom it affords students to come up with their own designs. Each group prepares several written and oral reports, refines its design in response to critique from a review panel of faculty and outside experts, becomes familiar with patent and market literature, and, of course, builds and demonstrates a prototype. A compressed version of this course was developed for use in high schools in the 1990s [5]. The systems courses, one in lumped parameter systems (electrical, mechanical, thermal, fluid, chemical, and resource systems, ordinary differential equations, and Laplace transforms), the other in distributed parameter systems and fields (elementary transport processes and electromagnetism, vector fields, and partial differential equations), are taken in the sophomore or early junior year. Regarded by students as the toughest courses in the major, they have the ambitious goal of teaching students how to apply a fairly small set of physical, mathematical, and computational methods across the widest possible sweep of engineering problems, and to see cross-disciplinary connections [6].

The required core is supplemented by an "elective" core. Students choose two from a set of four courses, each of which is taught so as to be applicable to more than one traditional engineering discipline: materials science; thermodynamics; control theory; discrete and probabilistic systems. The latter is the most recent addition to the core, recognizing the growing importance of probability models, *e.g.*, atomic systems, quality and reliability, information, and queuing [6].

Introductions to traditional branches of engineering are provided by a set of "gateway courses": digital electronics, analog electronics (electrical); solid mechanics, fluid mechanics (mechanical); chemical engineering, biotechnology (chemical); environmental engineering. Students choose two, from different branches, *e.g.*, fluid mechanics and chemical engineering, or biotechnology and environmental engineering, but not digital and analog electronics (both electrical) or solid and fluid mechanics (both mechanical).

Nearly all the fourteen core and gateway courses have labs and/or a significant team design project. Nine are offered twice a year, to keep class sizes relatively small and to facilitate scheduling with Dartmouth's unusual calendar. Four courses are offered in the summer term. Flexibility is particularly important in the sophomore year, when many students take study abroad terms. It also facilitates student participation in varsity athletics, the performing arts, or unusual internship opportunities.

In addition to the core and gateway courses, students have one engineering science elective and one other elective in engineering science, mathematics, or science. For the latter, a student interested in chemical engineering might choose a second course in chemistry; an electrical engineer might choose modern physics, linear algebra, or differential equations; an environmental engineer might choose a biology course in ecology or an earth science course in hydrology. All Dartmouth students are also required to complete a "culminating experience" in the major. In engineering sciences, this may be an honors thesis, the Bachelor of Engineering capstone design project (for those students continuing on), or a suitably advanced course, which may substitute for one of the engineering electives.

Free electives

After fulfilling all other degree requirements, most students have between four and eight uncommitted courses, which they may use for anything: additional liberal arts, even a minor or second major. About 10% of our students are double majors. Students continuing on for the B.E. may choose to use some or all of their free electives for engineering courses, thereby accelerating completion of the B.E.

Modified majors

Dartmouth College provides a convenient mechanism for interdisciplinary study: a student can combine six courses from one department with four courses from another department or area, resulting in a "modified major." Engineering sciences provides numerous such options. The modifying areas include other sciences, notably computer science and environmental science, but also economics and studio art. A separate engineering physics major is offered instead of a modified major with physics. The modified majors can all segue into the B.E. program; they also serve as preparation for graduate programs, *e.g.,* in applied physics, business, product design, or architecture. Today 38% of all engineering sciences majors are modified; the most popular options are economics, environmental sciences and studio art. The engineering sciences component of a modified major is somewhat different than the standard major, because of the need for synergy with the modifying discipline. Thus, modification with economics includes the introduction to engineering and the lumped and discrete/probabilistic systems courses, but also requires a course in operations research that would be an elective in the standard engineering sciences major. Descriptions of all the modified majors and of the engineering physics major may be read at the Thayer School website [7].

TECHNOLOGICAL LITERACY FOR LIBERAL ARTS STUDENTS

In the 1990s Dartmouth revised the general education requirements for all students to include a course in technology or applied science. Thayer School had long provided a few courses of interest to nonmajors, and some of our major courses (*e.g.*, introduction to engineering, digital electronics, and operations research) have few math and science prerequisites and are popular with students outside engineering, but our role has expanded and today we offer a spectrum of courses that meet this requirement for over half the student body. The topics include biosecurity, bioinformatics, future healthcare, nanotechnology, materials in civilization, product design, sailing, and how everyday devices work. We also offer two minors: one in engineering sciences and an interdisciplinary minor in materials (co-offered with the physics and chemistry departments).

POST-A.B. OUTCOMES

In assessing the outcomes of the A.B. in engineering sciences, current students and alumni were divided into four cohorts: those graduating in 2004-2006 (185 students), 1999-2001 (166), 1994-1996 (239), and 1984-1986 (187). Data were drawn from a combination of enrollment and alumni records. Because of the time required to complete graduate education, the most complete career information comes from the ten- and twenty-year cohorts. On the other hand, the current and five-year cohorts profile recent education choices.

The majority of recent A.B. students—63% of the five-year cohort (1999-2001)—continue into the ABET-accredited B.E. program; this represents a rising trend. Males tend to stay on for the B.E. at a slightly higher rate than females, 65% vs. 58%. The B.E. degree requires some additional preparation in math or natural science and up to an additional year of engineering study beyond the A.B.; admission to the B.E. program is automatic for students completing the A.B. Students tend to concentrate in a particular engineering discipline (electrical/computer, mechanical, chemical, biomedical, environmental, materials). The mean time to complete the B.E. is two terms beyond the A.B., so most B.E.-bound students do take some of their B.E. courses with their free A.B. electives. By a combination of free electives and advanced placement credits on entry to Dartmouth, about 20% complete the A.B. and B.E. in four years. Of the students who stay on for the B.E., 30% stay one more year and complete the Master of Engineering Management (M.E.M.) degree, combining engineering and business courses, before beginning their careers.

Examining the ten-year cohort, 54% completed the B.E. Overall, A.B.-only and A.B.-B.E. students completed higher graduate degrees at about the same rates (46% vs. 48%). About 16% of both groups completed M.S. or Ph.D. degrees; about 5% completed J.D. or M.D. degrees. The principal distinction is in the pursuit of a management degree. Nearly a quarter, 23%, of the A.B. graduates completed an M.B.A. in the ten years following graduation. A larger fraction, 29%, of B.E. graduates completed either the M.B.A. or M.E.M., with the M.E.M. being the more popular option. B.E. students, having a head start toward the M.E.M. by already being at Thayer School and surmising that the M.E.M. would be sufficient to their professional goals, tended to prefer it over the M.B.A. Similar statistics were obtained for the twenty-year cohort, with two exceptions: only 45% of the A.B. graduates stayed on for the B.E., and those B.E.s who subsequently sought a management degree took only the M.B.A., as the M.E.M. program was not in existence at that time.

In terms of career outcomes, alumni data reported career information for 68% of the ten-year cohort and 81% of the twenty-year cohort. We looked at both the kinds of companies they worked for and the positions they held. We found, overall, that both A.B. and B.E. graduates work principally in engineering and business, but also in law, medicine, and education, and a significant number achieve management positions. In particular, 44% of reporting A.B. graduates in the ten-year cohort are working broadly in technology careers (including architecture, product design, and information technology), as opposed to 50% of B.E. graduates; a slightly greater portion, 46%, of the A.B. graduates are in business or consulting, as opposed to 41% of the B.E. graduates. A.B. and B.E graduates are in law, medicine, education, or other professions at about equal rates (8%). A greater percentage of B.E. graduates are working as engineers (30%) as opposed to A.B. graduates (21%), who bypassed the B.E. and entered the engineering profession after taking M.S. degrees. A greater fraction of A.B. graduates, 28%, had achieved middle or senior management positions after ten years than B.E. graduates (20%). Twenty years out, the proportions of both A.B. and B.E. graduates in management positions are higher, 60% and 55% respectively. There is, not surprisingly, a greater tendency for A.B. graduates to enter the business world, particularly consulting, venture capital, investment banking, and financial services. Anecdotally, they credit their success in these fields to the liberal arts and to the problem-solving skills learned in team design projects.

SUMMARY

Dartmouth College has had a successful A.B. program in engineering sciences since the mid-1960s. Students take about a third of their courses outside math, science, and engineering, and are able to participate in foreign study programs as well as demanding extracurricular activities like varsity sports and performing arts. The engineering sciences major, comprising about half of the courses needed to graduate, is broad and interdisciplinary; specialization comes later for those students electing to continue into the ABET-accredited Bachelor of Engineering program. Options are increased through modified majors with other sciences, with economics, and with studio art. Graduates have proved to be well prepared for further study in engineering and careers in the profession, or for graduate study in other disciplines leading to careers principally in business but also in law, medicine, and education.

REFERENCES

1. National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century.* (Washington, D.C.: National Academies Press, 2005).
2. A. Mulrine, "Speaking the same language." *ASEE Prism* 15(4), 30-33 (2005).
3. W.P. Kimball, *The First Hundred Years of the Thayer School of Engineering at Dartmouth College*. (Hanover, NH: University Press of New England, 1971).
4. L. E. Grinter, "Report on evaluation of engineering education (1952-1955)." *J. Eng. Educ.,* 46(1), 25-63 (1955). Reprinted in *J. Eng. Educ.* 83(1), 74-95 (1994).
5. C.B. Muller and J.P. Collier, "Engineering concepts in the high school classroom: The Dartmouth/Thayer problem-solving methods." *ASEE/IEEE Frontiers in Education Conference* (1995).
6. U. Gibson, E. Hansen, W. Lotko, L. Lynd, U. Osterberg, B. Sonnerup, C. Sullivan, and L. Wilson, "An interdisciplinary core curriculum based on engineering systems." *ASEE/IEEE Frontiers in Education Conference* (2002). Online, http://engineering.dartmouth.edu/thayer/images/academicsadmissions/systems.pdf
7. http://engineering.dartmouth.edu/thayer/images/academicsadmissions/undergrad-modified.html

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