

External Analysis and Student Perceptions of a Human Centered Engineering Program

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Abstract

A recently formed department of engineering is offering a program entitled “Human Centered Engineering” as the only major it will offer. Having this unique and explicitly new kind of focus relative to most existing engineering programs (i.e., “human centered” as opposed to “mechanical”, “electrical”, or even “general” engineering) provides opportunities and risks. For example, program graduates may be—or may be perceived to be—better able to fulfill the ABET student outcome B5, “...understand ethical and professional responsibilities and the impact of technical and/or scientific solutions in global, economic, environmental, and societal contexts” yet less able to fulfill outcome B1, “...applying knowledge of mathematics and science and/or technical topics to areas relevant to the discipline”. The first cohort of students in the program are currently in their fourth year of study.

In this paper, the author (who is external to the institution being studied) will first overview the department’s curriculum and compare it to the most relevant peer programs found elsewhere. Next, the curriculum is analyzed in terms of its philosophical foundation as a multidisciplinary program. After that, data is presented on perceptions of the curriculum from the program’s students. This data came from formal interviews. Specific research questions for this portion of the paper are: 1) What are the perceived benefits and drawbacks of an interdisciplinary, human-centered engineering program?, 2) What topics, courses, and practices are perceived as the most and least valuable?, and 3) In what ways is it perceived that program graduates will graduate with advantage and with disadvantage?

Introduction

The founding of Boston College's Department of Engineering was a multi-year process initiated in 2014 [1]. Formal planning work commenced in 2018, the first faculty members were hired during the 2020-2021 academic year, and the first cohort of students arrived in Fall 2021. Those students are expected to graduate at the end of the current academic year.

The human-centered engineering program started from a desire to have an integrated science curriculum, noticing that funding agencies were increasingly supportive in the areas of energy, environment, and health. By combining integrated science with Boston College's mission to serve the common good, the faculty arrived at a desired program of “integrated science in action,” or, in a word, engineering. The engineering program is housed within Boston College's Morrissey College of Arts and Sciences, meaning the resulting curriculum must satisfy both the College’s liberal arts Core Curriculum and the requirements of an ABET-accredited engineering degree.

The department is plainly focused on being interdisciplinary. The department's name is simply "Department of Engineering", and the department offers only a single major / degree: a Bachelor of Science in Engineering. The department is housed within the College of Arts and Sciences, and students in the department must complete the same liberal arts Core Curriculum as students majoring in philosophy, economics, biology, or any other major within the Morrissey College.

The department is also plainly focused on being human-centered. The department's undergraduate program is entitled "Human Centered Engineering". The department's recently approved mission statement obligates themselves to "educate human-centered engineers and discover new knowledge in service of the common good" [2]. In addition, the program's educational objectives include supporting their graduates' ability to be "discerning about the role of engineering in society and critically reflect on their contributions to society professionally and personally" [2].

There are several aspects of Boston College's Human Centered Engineering program that are foundationally new or at least notably uncommon:

- centering an entire undergraduate program on the concept of human centered engineering;
- embracing practices of reflection;
- purposefully integrating much of the curriculum across ostensibly separate courses;
- teaching a very high proportion of the technical content of the degree 'in-house' by the engineering department, as opposed to by mathematics and science departments; and
- requiring a deep liberal arts core alongside an extensively project-based technical core.

The current student population consists of approximately 25 students in the first cohort and approximately 50 students in each of the subsequent cohorts [3]. At the time of this paper's data collection, there were 10 full time faculty in the department, two at the full professor rank, one at associate rank, and seven at assistant rank. Seven of the faculty members were tenured or tenure track, and the other three were non-tenure track professors of the practice. Tenure track faculty are expected to have an active research program, albeit without graduate student research assistants. While a few different academic backgrounds are present among the faculty, there is a noticeable concentration in areas related to bio- and environmental engineering. These areas correspond to the department's focus themes: Health, Energy, and Environment.

Methods

Data presented here about Boston College, their Department of Engineering, and its engineering curriculum was obtained from publicly available printed and electronic publications. Information from comparator programs was obtained from their publicly available websites and from individual communication. Also included in this report is information based on formal interviews of students and faculty. To recruit faculty and administrators, individual messages

were sent requesting their time. To recruit students, I made oral announcements in several of the first- and third-year courses requesting volunteers, and interviews were then scheduled individually with respondents. A future paper will include data from the faculty interviews to compare their perceptions with those of the students.

The process of the formal interviews and subsequent analysis was approved by the Institutional Review Boards of both Boston College and Northeastern University (the author's institution). For the formal interviews, signed consent forms were obtained. Audio recordings of the interviews were made, used to correct automated text transcripts, and then deleted. The text transcripts were anonymized and saved for analysis. Limitations of the interview portion of this work as presented in this paper arise from the small numbers of participants (4 students, 8 faculty) and the voluntary—and therefore self-selected nature—of participation.

Curriculum Summary and Comparison

As in most engineering programs, the degree requirements are substantial and students have less flexibility in course selection relative to other majors. In total, the degree requires 126 credits from the following courses:

- 8 humanities (24 credits)
 - 4 language (12 credits)
 - 2 social science (6 credits)
 - 1 writing (3 credits)
 - 3 math (11 credits)
 - 2 science (8 credits)
 - 15 engineering core:
 - 3 design (10 credits)
 - 2 modeling / analysis / experimentation labs (4 credits)
 - 2 programming / data science (7 credits)
 - 4 disciplinary foundations (16 credits)
 - 4 project courses (11 credits)
 - 4 engineering advanced electives (11 credits)
 - 1 open elective (3 credits)
 - 8 reflection seminars (0 credits)
-
- non-technical
- STEM

Any categorization like this is necessarily reductive. I have taken significant liberty in choosing the labels for the engineering courses, especially as several of them include content that falls in more than one of my labels. Of the 126 total credits required for graduation, 45 are non-technical, 78 are STEM, and 3 are open electives. The engineering faculty teach just under half of the required credits (62) in addition to teaching all the 0-credit reflection seminars.

In very broad terms, the four courses that I've labeled as disciplinary foundations cover the basics of mechanical, electrical, chemical, and industrial engineering. Somewhat more precisely, the contents are: 1) mechanical statics and materials science; 2) circuits; 3) transport processes; and 4) systems analysis, engineering economics, and lifecycle analysis. These courses are taken in the second year.

Of the three courses I've labeled as "math", only two are taught by the mathematics department: Calculus 1 and Calculus 2. The third course, Advanced Engineering Math, is taught by the engineering department. There is no requirement to take a course on Calculus 3, Differential Equations, Linear Algebra, or Statistics; instead, topics from these courses are embedded as learning objectives within engineering courses.

There is a continuity of project-centered courses through the student experience. The four courses that I have labeled as project courses include one 2-credit course in the second year, one 3-credit class in the junior year, and a two-semester, 6-credit capstone sequence in the senior year. While these four courses are centered almost entirely on work on a single project, many of the other courses taught by the department include significant project work.

The reflection seminars are unique to Boston College's engineering curriculum. Reflection seminars are not generally a requirement for other majors at Boston College, though aspects of reflection can be found in other components of the Boston College environment. No other engineering program found by the author has something comparable to these seminars. They are worth 0 credits, but students must receive a passing grade for eight semesters as a graduation requirement. Seminar meetings are once a week for one hour, and students in different cohorts do not have reflection together.

The activities used in reflection seminars include small and large group discussions, journaling and similar self-expression activities, team design challenges, case studies, and guest lectures. Topics included in the reflection seminars include personal character development, cultural / societal implications of engineering work, stakeholder analysis, teamwork skills, intra-cohort formation, inter-cohort advising, academic skills development, career exploration, and professionalization.

There are several programs that make for useful curricular comparisons. Here, I will compare with programs at Dartmouth College[4], Santa Clara University [5], Smith College [6], Swarthmore College [7], University of San Francisco [8], and Wake Forest University [9]. These institutions were chosen as they are all generally structured as liberal arts institutions and offer an ABET-accredited general or interdisciplinary engineering program. Interestingly, Dartmouth explicitly uses the phrase "human-centered" in much of their programmatic self-description, and they offer a Human-Centered Design minor.

Dartmouth, Santa Clara, Smith, and Wake Forest each have engineering core requirements that are structurally similar to Boston College's, so this group will be discussed first. All four curricula in this group have significantly less design / analysis content (1 or 2 courses vs. 5) and fewer project-focused courses (3 at Dartmouth and Santa Clara, and only the 2 semesters of senior capstone at Smith and Wake Forest vs. 4 distributed through the curriculum). All of these

schools require, like Boston College, disciplinary foundations courses. At Dartmouth, students select two foundations courses from among mechanical, electrical, chemical, or environmental engineering and add two transdisciplinary foundations courses (e.g., thermodynamics). The other three all require foundations courses in mechanical engineering and in electrical engineering, with Smith and Wake Forest adding a course in chemical engineering, while Santa Clara instead adds courses in bioengineering and in civil engineering. Since Santa Clara has disciplinary departments, their foundations courses are taught by faculty in the corresponding departments rather than from within the general engineering program.

Beyond the engineering core, the curricula at these schools have idiosyncratic differences from Boston College's program. Dartmouth requires that the engineering electives form a concentration, most typically within one of the traditional disciplines. Santa Clara adds a core course in entrepreneurship. Smith reduces programming to one course but adds a course on fluid mechanics, a second course on thermodynamics / conservation, and requires an additional engineering elective (5 vs. 4). Wake Forest adds a course on experimental methods and instrumentation and—interestingly—requires 14 credits of engineering electives fulfilled mostly via two-credit courses.

The curricula at the other two comparators, Swarthmore and University of San Francisco (USF), are significantly different from those at the previous group.

Swarthmore has a unique engineering core of twelve classes: seven required and five elective. The required courses are: two project-based design courses (one in the first year and a one-semester capstone); three disciplinary foundation courses in mechanical engineering, electrical engineering, and computer engineering; mechanics of materials; and analysis. Students are required to pick electives so that they form a coherent program, which can be self-designed or based on a traditional discipline of electrical, computer, mechanical, or civil engineering.

At USF, there are no required disciplinary foundations courses—students never need take a course on circuits or on mechanical statics. Second, the program focuses very strongly on two topics: 1) project-focused design learning, with five courses including two of capstone; and 2) modeling / programming, with four courses. Added to this core is a course on instrumentation, a two-credit course on professionalization, and a zero-credit course on fabrication and shop skills. All students must pick a concentration, realized via the choice of four corresponding engineering elective courses. Available concentrations are Electrical & Computer Engineering, Environmental Engineering, and Sustainable Civil Engineering.

Curriculum Analysis

Boston College's human centered engineering program occupies a unique niche. In general, the number of graduates from interdisciplinary engineering programs is small, hovering between 1 - 2 % of all engineering degrees in the US since 2011 [10]. In 2003, Newberry and Farison created a useful classification system of general engineering programs, calling them

philosophical, instrumental, or flexible [11]. Philosophical programs are those where a general or broad-based engineering curriculum is seen as intrinsically advantageous. Instrumental programs are those where a general engineering program is used as a centralized support for curricula that are essentially discipline-focused. Such a program might be found, for example, where a small program needs the administrative efficiency of a single engineering department despite offering degrees that focus on traditional engineering disciplines (perhaps through student selection of a concentration area). Finally, flexible programs are those that exist in parallel with traditional engineering disciplines and are offered as a flexible way to combine an education in engineering fundamentals with business, pre-law, pre-med, or other less traditional engineering career path. In 2011, Grondin classified the 41 ABET-accredited general engineering programs then existent and found 6 were philosophical, 27 were instrumental, and 8 were flexible [12].

I would classify Boston College's Human Centered Engineering major as philosophical, despite the fact that students choose an engineering concentration. The concentrations on offer, health, energy, and environment, all lie across traditional disciplinary boundaries, and the human-centeredness emphasizes the unique and intrinsic advantage of the interdisciplinary approach. Newberry and Farison describe philosophical programs as small, "capable of filling a unique niche," and productive of "generally and liberally educated engineer[s]" [11]. The authors further note that the motivation for programs of this classification is that "the current trend toward complex, highly integrated systems and global markets calls for future engineers that are more broadly educated, more flexible, and more sensitive to non-technical concerns." Two challenges they associate with these programs are: 1) a job market that seeks graduates with disciplinary expertise and 2) finding faculty interested in interdisciplinary undergraduate education more than their disciplinary affiliation. For reference, the six programs classified as philosophical by Grondin in 2011 are at: Dartmouth, Swarthmore, Harvey Mudd, Southern Utah University, University of Southern Indiana, and Colorado State University-Pueblo [12].

A quantitative evaluation of Boston College's credit requirements can be compared against data compiled in 2023 by Bielefeldt [10]. In this paper, curricular (and other) data is compiled from schools with an ABET-accredited interdisciplinary engineering program. Of the 77 schools where credit-hour information could be compiled, between 120 and 147 total credits were required to graduate, with a median of 128 credits. ABET requires a minimum of 120 total credits. Boston College requires 126 total credits, exceeding ABET's requirement yet just below the median in the dataset of accredited programs.

Another requirement of ABET is that a minimum of 75 credits come from math, science, computing, or engineering. Thus, ABET expects STEM content to be about 62.5% of the degree if one uses the minimal 120 credits (or 58.6% if one uses the median value of 128 credits noted above). All of the accredited general engineering programs included in Bielefeldt's study exceeded 62.5% STEM credits, with a median value of 73.9% [10]. Boston College requires 78 STEM credits, 61.9% of the total. This proportion of STEM content is thus lower than any in Bielefeldt's database, though ABET's requirement on the minimum number of STEM credits is met.

The credits that are taken specifically from within engineering (as opposed to all of STEM) can be compared using a different dataset [13]. In this dataset of 20 institutions that offer an interdisciplinary engineering degree, the number of required credits that are taken within engineering range from 48 to 90; as a proportion of the total credits, the range is from 37.5% to 67.2%. In these metrics, Boston College is near the median with 62 credits, 49.2% of the total, taken from engineering faculty. Taken together with the previous result—a relatively low proportion of STEM credits in the major yet a median proportion of engineering credits—these results show that the STEM content of a Boston College engineering major is highly engineering-focused.

Boston College's engineering core of 15 classes includes a variety of cross-disciplinary topics. There is predominantly analysis, design, and programming topics in the first year and then foundational mechanical engineering, electrical engineering, chemical engineering, and industrial engineering in the second year. The third year and fourth year largely focus on project courses and engineering electives within the student's chosen concentration. As befits an engineering program, there are multiple lab courses, and many of the courses—even those not titled “project” or “lab”—meet in active learning classrooms and include plenty of hands-on work.

One of the key drivers of Boston College's curricular design is combining the rigorous technical education needs of an engineering program that meets the ABET requirements with the broad liberal arts education needs that meet the Morrissey College of Arts and Sciences requirements. A related driver of curricular decisions is balancing the benefits of a broad expertise inherent to an interdisciplinary engineering degree against the depth provided by a traditional, discipline-focused engineering degree. These tensions are not unique to Boston College. In an appendix to the National Academy of Engineering report on *Educating the Engineer of 2020*, it is noted that questions of “what to include in tight curricula, ... how much specialization there should be at the undergraduate level, ... and how to meet the needs and expectations of society all seem timeless” [14]. One of the ways the Boston College curriculum alleviates these tensions is by distributing foundational content across multiple classes, in ways that will be described in the following paragraphs.

Analysis of Student and Faculty Perceptions

The interview process involved a number of predefined questions (included in Appendix 1). The research questions considered in this paper were not directly asked during the interviews but rather came out of responses across a range of questions. Interview transcriptions were read to pull out thoughts that align with the three research questions considered in this paper.

RQ1: What are the perceived benefits and drawbacks of an interdisciplinary, human-centered engineering program?

The most common benefit expressed by the students was that the program provided an integrated view of their engineering work and its purpose. Student described this aspect as “working more than one just part of one part of your brain,” “educat[ing], like, the whole person”, and a “holistic version of engineering while still getting a liberal arts education... incorporating those two parts of my life together sounded like a really unique opportunity.” Another theme that emerged in this area was the mixture of people in the program. One student explained, “[we] work with a bunch of people that may have different interests as you, and you also get to experience all sorts of different professors with different specialties.” Finally, students expressed that the integration of the human-centered approach was a key benefit. “All of the classes...taught in-house, meaning in the engineering concentration, are directly aligned with the course content of the classes that are outside of the core focus,” said one student. The projects, said another, are “realistic...face head-on problems” and “[we are] looking at the people first and solving for the people, not [just] looking at the problem.”

Students were able to express a few perceived disadvantages of an interdisciplinary, human-centered program. They mentioned that the newness and uniqueness of the program can be “difficult to express” to those outside the program. Along those lines, students expressed a desire for some “more traditional engineering classes just in order to...tie in, like, this is how things were done, this is how we're changing it, this is...why we're doing that, and how we're going to move forward with this new [human-centered] perspective in mind.” Finally, one student noted that having a relatively small general engineering program meant that there are few elective classes within any given area of student interest.

RQ2: What topics, courses, and practices are perceived as the most and least valuable?

In the interviews, students expressed a number of things as being valuable. Every student mentioned something about the curricular integration of concepts between courses. As mentioned in the program analysis above, this integration is facilitated by having so many of the courses being taught ‘in-house’ by department faculty. Also mentioned by every student were teamwork and projects. The curriculum includes project work every year, and students especially found value in “hands-on, real clients or on campus-projects where you can actually tell that you're making an impact because things are changing.” Two of the students specifically called out the instruction in the historical context of engineering work as being valuable. The students all mentioned specific engineering topics or lab activities that felt valuable to them (e.g., a circuit lab where students built and calibrated a working electrocardiogram). The variety in which topics were mentioned suggest that these represented individual preferences and character more than programmatic character.

No consistent themes emerged from the student interviews about program aspects that are less valuable, although formal interviews in a campus office may not be the most conducive environment to a student describing such things. Each student expressed a range of feelings about the reflection seminars. There seemed to be both appreciation of the inherent value of the

reflective practice and the difficulty in getting fellow students to take serious the requirements for a 0-credit course.

RQ3: In what ways is it perceived that program graduates will graduate with advantage and with disadvantage?

Students reported being optimistic about their future prospects and field of work. This is due, in part, because students have trust in the reputation of Boston College. It also comes from a recognition in the multidisciplinary nature of the problems they hope to solve. For example, one student said, “earning this engineering degree with a human-centered focus is going to hopefully put me in a better direction to find a job that has to do with either something environmental, whether it's like food deserts, or renewable energy, or reducing carbon footprint, or something more biological that has to do with human health.” Another student thought that having a multidisciplinary undergraduate engineering degree would make it easier for her to apply to a wider variety of graduate engineering programs. Students expressed confidence that the program was defining, to use one student's words, “the future of engineering here.”

Conversely, students expressed some nervousness because the program focus is new and less well known. When discussing future plans, a student again mentioned the difficulty in communicating what human-centered engineering is (to a potential employer).

Conclusions

The Human Centered Engineering program at Boston College emphasizes interdisciplinary learning alongside the engineer's role in society. By integrating an ABET-compatible technical curriculum with a liberal arts foundation, the program aims to produce engineers who are not only technically proficient but also aware of the societal, ethical, and environmental implications of their work. Unique features of the program include the reflection seminars and the integration of human-centered design principles. The curriculum's emphasis on project-based learning and interdisciplinary collaboration fosters a learning environment where students can develop both their technical skills and their ability to work in diverse teams.

Student perceptions suggest they recognize the benefits of this integrated approach, noting the value of a holistic education that combines technical expertise with a broader understanding of engineering's impact on society. However, the students also perceive challenges, such as the need to clearly communicate its unique focus to external stakeholders and the limited availability of elective courses within specific areas of interest.

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Appendix 1. Interview Script

I have now started the audio recording.

Thank you for agreeing to take part in this research by sitting down for an interview. I hope this takes us about 30 minutes. You can stop or pause the interview at any time, and you can skip any question you don't want to answer. Please answer each question as you see fit. There are no bad answers, and it's ok if you later want to clarify or modify anything you've said previously as you continue thinking. I want to know your honest opinions. Your name will not be collected or associated with the interview transcript, only an anonymous ID number. Do you have any questions about what we'll be doing?

1. If you feel comfortable sharing, how do you identify yourself? You could include such things as gender, racial/ethnic/cultural heritage, and what part of the world you spent your childhood.
2. If you feel comfortable sharing, please describe your education prior to being at Boston College.
3. How many semesters have you been [enrolled / working] in Boston College's engineering program?
4. How has your experience at Boston College generally and in Boston College's engineering program been so far?
5. Why did you choose to [enroll / work] in Boston College's engineering program?
6. What other schools and departments were you strongly considering before choosing this one?
7. [students only: What have you heard from friends who are currently enrolled in engineering programs at other schools? How do you feel your experience compares to theirs?]
8. [faculty only: How is this engineering department and its curriculum the same as and different from engineering departments and curricula at other institutions?]
9. What does interdisciplinary engineering mean to you? What makes this program interdisciplinary?
10. What does human-centered engineering mean to you? What makes this program human-centered?
11. What are some ways the human-centered approach is used or learned?
12. To what extent or in what ways do you feel Boston College's engineering program is preparing [you / students] to be an engineer out in the world?
13. What parts of the Boston College engineering curriculum have been unexpected or surprising?

14. What are some good things about this program in terms of what [you / students] have learned or will learn?
15. What would you like to see be different about this program in terms of content or structure?
16. What topics, courses, and practices have been the most valuable to [you / students]?
17. Where does reflection sit in the curriculum?
18. [faculty only: What would you advise an institution that wanted to copy aspects of what this department is doing?]
19. [faculty only: What pain points or tensions, if any, exist with an engineering curriculum at Boston College?]
20. Do you have any additional thoughts that you would like to share about the topics we've discussed today, or is there anything you'd like to clarify or expand on?