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Teaching STS to Engineers: A Comparative Study of Embedded STS Programs

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Abstract

The field of Science, Technology, and Society (STS) draws from a full range of disciplines in the social sciences and humanities to examine how science and technology simultaneously shape and are shaped by society, including politics and culture. Although engineering educators and employers have recognized the importance of professional (nontechnical) skills for over 100 years, the instructional strategies and institutional arrangements necessary to help students develop these skills have not yet settled into a widely adopted standard. Many engineering programs have turned to STS to provide students with conceptual tool kits to think about engineering problems and solutions in more sophisticated ways. Some programs feature standalone courses on the sociocultural aspects of technology and engineering, often taught by faculty from outside the engineering school. Others incorporate STS material into traditional engineering courses, e.g., by making ethical or societal impact assessments part of capstone projects.

This work in progress paper draws on the research team's personal experience to examine the character of an atypical, but potentially very powerful, model: STS programs embedded in engineering schools in the United States and Canada. The authors expand on previous scholarship by Kathryn Neeley, Caitlin Wylie, and Bryn Seabrook in "In Search of Integration: Mapping Conceptual Efforts to Apply STS to Engineering Education," as presented at the 2019 ASEE annual conference, to examine how STS is incorporated in engineering education. While Neeley, Wylie, and Seabrook focused on broad trends within a single, large professional society (ASEE), this study focuses on two particular embedded STS programs, with an emphasis on how the research team describes STS for engineers and encourages meaningful integration.

What does the field of STS offer engineering students? What core STS concepts and approaches do we teach to engineering students? The authors explore these and other related questions by analyzing how a small sample of programs became embedded within engineering schools, how each program attends to accreditation outcomes, and how they approach teaching STS to engineers. In future work, the research team hopes to create a preliminary typology of embedded STS programs, explore the term "embedded," and find commonalities in the courses offered in embedded programs.

Keywords

Science and Technology Studies
Embedded STS
Engineering Education
Engineering Problems and Solutions

INTRODUCTION

In a retrospective historical account titled "A Century of ASEE and Liberal Education," O. Allan Gianniny (1995) highlighted the recursive nature of attempts to optimize the contribution of the humanities and social sciences (HSS) to engineering education [1]. Among the numerous reports on the improvement of engineering education, Gianniny cites William Wickenden's 1930s *Report of the Investigation of Engineering Education, 1923-1929*. In the chairman's report that introduces Vol. 1, Charles F. Scott expresses aspirations and concerns that strongly resemble those expressed over the last 20 years: "the functions of the engineer have become more complex and are interrelated with many activities of modern life…. The strictly technical activity is comprised in engineering but it is not a definition of it. What engineering education must have is a guiding philosophy based on a clearer visualization of the place of engineering in modern life" [2], p.12.

This historical perspective allows engineering educators to see that the aspirations expressed in 2004's *The Engineer of 2020: Visions of Engineering in the New Century* are more a tradition than a novelty [3]. What is relatively new is the emergence of the field of Science, Technology, and Society (STS) and, in particular, attempts to integrate STS into engineering curricula. STS provides conceptual frameworks that enable students to see engineering problems and solutions in sociotechnical terms. As Neeley, Wylie, and Seabrook demonstrated in their 2019 paper [4], engineering educators have considered the application of STS approaches in engineering since at least the mid-1990s. Furthermore, attention to STS among engineering educators has shifted toward embedding sociotechnical thinking and developing increasingly sophisticated methods of assessment.

This paper builds on the work of Neeley, Wylie, and Seabrook to examine different approaches to integrating STS into engineering curricula and consider the effects of this integration on programs and faculty members. Institutional approaches to integrating STS content into engineering classrooms vary widely. Some programs feature standalone courses on the sociocultural aspects of technology and engineering, often taught by faculty from outside the engineering school. These courses may be required for all engineering students or, in the case of Virginia Tech's *Engineering Cultures* course, may be optional but popular electives [3]. Others incorporate STS material into traditional engineering courses, e.g., by making ethical or societal impact assessments part of capstone projects.

In this paper, the research team discusses an atypical approach to including STS content in the engineering curriculum: the embedded STS program. In this context, "embedded" describes an STS unit that exists - organizationally and often also physically - within a larger engineering space. Such programs hold great potential for contributing to engineering education in a distinctively strong while also efficient way, but there are multiple obstacles that stand in the way of realizing their potential at scale. The remaining sections of this paper provide an overview of the advantages and disadvantages of various approaches to optimizing the contribution of the humanities and social sciences to engineering education; describe and compare two programs that self-identify as embedded; present a preliminary scheme for organizing thinking about the fundamental tasks of embedded programs; and identify areas of emerging consensus and further research.

Embeddedness as a "Third Way" with Both Advantages and Challenges

Such programs are located within American engineering schools or Canadian faculties of engineering and tend to employ faculty with training in STS or related disciplines. They are mandated to teach STS concepts to undergraduate engineering students, often fulfilling specific accreditation requirements. The embedded STS department model can thus be understood as a response to these requirements chosen by a small number of engineering programs from among a variety of other avenues of response. Perhaps the most common response chosen has been to require engineering students to fulfill the non-technical accreditation requirements by enrolling in ethics courses or writing courses offered by departments outside of engineering. Another common response has been to require that engineering professors include social and ethical considerations in their technical courses or to include writing assignments that can be used to develop and assess the communication competency.

Both of these responses, while often good faith, laudable attempts at addressing non-technical accreditation requirements, suffer from well-known shortcomings. Those tasked with introducing engineering students to ethics and communication skills who are outside of the engineering field are often not well situated to address ethics ***of technology*** or the kind of ***technical*** writing and communication that is relevant to engineering students. On the other hand, when the task of introducing engineering students to ethics and communication skills is assigned to engineering faculty, they are often not well situated to address ***ethics of*** technology or the kind of technical ***writing and communication*** that is relevant to engineering students. The embedded STS department is a "third way" of sorts. By giving the task of introducing engineering students to STS professors whose research and teaching focuses precisely on the intersection of technology and society—and often more specifically on engineering education—engineering faculties and schools are able to confidently address the shortcomings of the two approaches described above. It is with this "third way" in mind that we use the term "embedded department."

Embedded STS programs enjoy nominal membership in the engineering faculties in which they are embedded. This situates the STS scholars that comprise these programs ***within*** the engineering faculty. This positionality creates opportunities for engagement with engineering department not available to STS scholars who engage from without. This is especially the case when the privileges of membership extend beyond the nominal and place members of these departments or programs in positions of power or influence such as faculty committees and faculty governance. Playing such roles allows faculty to effect real change through curriculum design, research, hiring, and tenure committees. As we will show below, another area in which real change can be affected from these embedded departments is accreditation. We have found that embedded STS programs are afforded unique opportunities to boldly experiment with engineering curricula when framing proposed changes as responses to non-technical accreditation requirements.

Although embedded STS programs may be organizationally and spatially co-located with engineering faculties, that positioning is no guarantee of intellectual integration. Embedded programs pose undeniable challenges to faculty. Administrators and other engineering faculty often understand the programs as "service units" that serve a supplementary role in comparison with other engineering programs. Faculty may struggle to define or maintain their professional identities, and to pursue their research goals. The worry of cooptation and issues surrounding the problem of "going native" well known within ethnography abound. Additionally, the strength of the STS program model -- that of having content experts on social/ethical studies of technology and technical communication housed within an engineering department -- can sometimes prove to be a weakness. When members of the engineering faculty know they have a specialized department composed of content experts, they are perhaps less likely to treat non-technical considerations within their own courses since they have a department to "handle" those things. However, embedded programs also present singular opportunities for critical participation in the training of engineers. We return to this topic later under the heading of "Living: Faculty Experience in Embedded Programs."

This paper examines the history, mission, and curriculum of two embedded STS programs: the Centre for Engineering in Society at Concordia University in Montreal, Quebec, Canada, and the Department of Engineering and Society at the University of Virginia in Charlottesville, Virginia, United States. As mentioned earlier, other institutions incorporate STS courses in engineering education; however, the two institutions examined in this paper provide evidence for comparison not just internationally, but also historically, since one program is significantly newer than the other.

Through synthesis of works published by faculty members in the two programs, as well as a comparison of syllabi from STS courses taught to undergraduate engineering students at both institutions, the authors describe how faculty in embedded STS programs *define*, *justify*, and *live* STS for engineers. The authors show how both programs have evolved, how they approach their STS pedagogy, and how they alternately resist and embrace their embeddedness. They explore how accreditation requirements in Canada and the United States have helped to shape the two programs. Ultimately, they suggest that the embedded STS program is a distinctively strong approach to integrating sociotechnical thinking in engineering curricula. The tensions and opportunities posed by embedding STS within engineering persist across borders and accreditation systems. This paper lays the groundwork for future investigations of embedded STS programs, including direct comparisons of faculty and student experiences.

CENTRE FOR ENGINEERING IN SOCIETY, CONCORDIA UNIVERSITY

History

Concordia University's Centre for Engineering in Society (CES) began in 2005 as the General Studies Unit. Located within the Faculty of Engineering and Computer Science (since 2019, the Concordia School of Engineering and Computer Science), the General Studies Unit initially included tenure-stream faculty with degrees in rhetoric and communication and later grew to include others with expertise in public policy and science and technology studies. In creating the program, the faculty intended to centralize subjects that were common to all undergraduate engineering programs, including general mathematics and programming alongside technical writing and the social impact of technology. The General Studies Unit would function as a "service department" in the sense of carrying out the specific mandates of the faculty of engineering.

As the unit grew, its faculty members began to supervise and co-supervise students, gain the support of key champions, and articulate their own mission and vision. The intention for the unit to teach ***all*** common introductory engineering courses was abandoned, and the unit focused instead on developing required courses in engineering ethics, technical communication, and science and technology studies. Faculty members took on increased responsibilities and became more integrated into the engineering faculty as a whole, alternately embracing and resisting the "service department" designation [5]. Faculty members were enthusiastic about working to improve the practice of engineering and computer science students, but the unit's lack of individual degree programs constrained research and mentorship opportunities. A 2008 faculty report and five-year plan for the unit's development identified these frustrations and emphasized that existing solely in a service role would be untenable for tenure-stream faculty [6].

In 2011, the General Studies Unit was renamed the Centre for Engineering in Society (CES). While CES still grapples with its history and perceived identity as a service unit, it now offers one graduate certificate program in "Innovation, Technology and Society" and participates in an institution-wide, individualized, interdisciplinary graduate program (INDI) for masters and Ph.D. students. CES faculty pursue their own research agendas and participate fully in both the university's administrative structure, and numerous interdisciplinary research and outreach efforts. Discussions about its departmental identity and its role within the engineering faculty continue within the Centre [5].

Mission and Approaches

CES is involved in training undergraduate and graduate engineering and computer science students in a number of ways. This paper focuses on CES's intersections with Concordia University's core undergraduate engineering curriculum. CES faculty coordinate and teach three courses required for all undergraduate engineering students, coordinate a mandatory engineering writing test (EWT) for newly admitted engineering and computer science students, and work with undergraduate capstone design teams to incorporate constructive technology assessment approaches into the design pedagogy in the capstone design course. Together, the EWT, the three core courses, and the capstone experience comprise a scaffolded approach to understanding engineering as a sociotechnical field and practice. *ENGR 201: Professional Practice and Responsibility*, which most students take during their first year of study, introduces students to engineering in its social context. The course covers the history of the engineering profession, an overview of the professional system in Canada and Quebec, and a case study-based introduction to engineering ethics. *ENCS 282: Technical Writing and Communication* builds on this foundation to develop students' practical communication skills, reinforcing the idea that communicating complex ideas to colleagues, clients, and the public is an important engineering skill. Prior to enrolling in *ENCS 282*, students must demonstrate their command of basic writing and analytical skills by passing the EWT. *ENGR 392: Impact of Technology on Society* presents more advanced concepts related to technology, engineering, and society, and includes the most straightforward STS content of any CES course. Finally, the CES component of the capstone course requires students to perform a "Real-Time Technology Assessment" of their own project, incorporating sociotechnical thinking into the engineering design process.

CES members have reflected a great deal on how to best maintain the critical eye toward technology and society that they bring from their STS training while participating in the practical, day-to-day goings on of an engineering and computer science faculty. In a piece in the journal *Engineering Studies* (the inaugural paper in the journal's "Critical Participation" category), CES faculty described the tensions that result from the position of CES within a faculty of engineering. Locally, the place of CES poses a consistent threat of co-optation, but also provides great potential for shaping engineering courses. On a global level, CES faces the question of how best to harness the opportunity provided by new CEAB graduate attributes and scale up their critical perspectives into the broader academic landscape:

> Our challenge is to craft an Engineering Studies identity that is sensitive to the potentially increased danger of co-optation while also crafting an identity that does not alienate us from those in the mainstream of the prevailing engineering education discourse who, for now, recognize us as important and necessary voices in reshaping the engineering curriculum. Yet, the image of a service department remains a key constraint. CES' efforts at participation (critical or otherwise) remain hamstrung by its institutional location. Our desire to reconcile the twin pulls of forming a critical Engineering Studies identity with our location in a traditional engineering faculty has generated a great deal of reflection on the particular departmental model CES ought to embrace [5].

Alongside the challenges their position poses, CES members enjoy some unexpected advantages. The department enjoys the same rights and responsibilities as Concordia University's other engineering departments, despite being considerably smaller than most and lacking its own degree program. Faculty in CES participate in the administrative operation of the university just as faculty from other departments do. Their position between engineering and the humanities and social sciences has also enabled CES members to easily interact with colleagues from across the university, to take on administrative roles that have normally been reserved for senior faculty, and to consistently advance up the career ladder. Finally, CES has been able to facilitate frequent interdisciplinary discussions and initiatives within the university.

Accreditation

The Canadian Engineering Accreditation Board (CEAB) specifies 12 attributes which graduates of accredited engineering undergraduate programs must possess and are summarized in Figure 1 below. These attributes differ from previous CEAB accreditation criteria because they require—for the first time—that engineering faculties across Canada demonstrate that they are producing students capable of thinking through the ethical, legal, social, and environmental implications of their engineering practices. Programs must collect data and incorporate it into a "continuous improvement" process regarding student performance. Because they do not have experts in the academic specialties most relevant to the non-technical (usually called "complementary") skills, most engineering degree programs across Canada are struggling to meet the new requirements.

The institution must demonstrate that the graduates of a program possess the attributes under the following headings. The attributes will be interpreted in the context of candidates at the time of graduation. It is recognized that graduates will continue to build on the foundations that their engineering education has provided.
Engineering programs are expected to continually improve. There must be processes in place that demonstrate that program outcomes are being assessed in the context of these attributes, and that the results are applied to the further development of the program.

1. A knowledge base for engineering
Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.
2. Problem analysis
An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.
3. Investigation
An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.
4. Design
An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, economic, environmental, cultural and societal considerations.
5. Use of engineering tools
An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.
6. Individual and team work
An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.
7. Communication skills
An ability to communicate complex engineering concepts within the profession and with society at large. Such abilities include reading, and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.
8. Professionalism
An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.
9. Impact of engineering on society and the environment
An ability to analyze social and environmental aspects of engineering activities. Such abilities include an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society; the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.
10. Ethics and equity
An ability to apply professional ethics, accountability, and equity.
11. Economics and project management
An ability to appropriately incorporate economics and business practices including project, risk and change management into the practice of engineering, and to understand their limitations.
12. Life-long learning
An ability to identify and to address their own educational needs in a changing world, sufficiently to maintain their competence and contribute to the advancement of knowledge.

Figure 1: Twelve Attributes of the Canadian Engineering Accreditation Board [7]

In most cases, technically oriented engineering professors are being asked to incorporate ethical, legal, and social issues into technical courses. This has resulted in a great deal of push back from these professors who are rightly frustrated that they are being asked to cover material for which they lack expertise (or often even familiarity). Because of the expertise possessed by faculty in the CES, the CES faculty saw the new requirements as an opportunity, and [Name of Institution] was much less challenged than engineering faculties without STS expertise.

CES courses are primarily responsible for assessing 4 of the 12 attributes: communication skills, professionalism, impact of engineering on society and the environment, and ethics and equity. Others are assessed through a combination of CES and non-CES courses, or through non-CES courses alone. Most CES courses include assessment of numerous attributes. However, as the names of the courses themselves suggest, CES's core engineering courses are each focused on one or two individual attributes: *ENGR 201* on professionalism and also ethics and equity; *ENCS 282* on communication skills; and *ENGR 392* on the impact of engineering on society and the environment.

These courses illustrate the ways CES harnessed the potential of the destabilization the new accreditation practices and standards created by implementing and evaluating a novel approach to teaching engineering students how to incorporate ethical, legal, and social considerations into engineering design courses. Borrowing from the literature on constructive technology assessment and responsible research and innovation, we have developed a three-part process that walks engineering students engaged in project design courses through the process of incorporating these considerations into the research and design phases of their projects. Following the literature on social construction of technology (in particular Guston and Sarewitz, 2002), we call this pedagogical approach "real-time technology assessment" (RTT). The aim of this approach is to provide an explicit mechanism for observing, critiquing, and influencing social values as they become embedded in innovations. This approach to technology assessment differs from traditional models that typically focus on "impact assessments" of what the effects of a new technology are on society *after* the technology has been introduced. Real-time technology assessment attempts to incorporate potential societal implications into the actual "real-time" design processes that go into the construction of a new technology. It differs from other traditional pedagogical approaches to teaching ethics as well. This assessment mechanism allows students to engage with *real* technologies that have *real* social, ethical, and legal dimensions. In this way, students are encouraged to learn experientially through a real-world technology that is being developed in real-time.

Through a series of negotiations with each of the four departments in the engineering faculty at Concordia University, we have secured agreements with each department to work with the final year capstone design courses. Under these agreements, a lecture at the beginning of the Fall and Winter semesters familiarizes each capstone cohort with the idea of real-time technology assessment. After the lecture at the beginning of the semester, each capstone team makes an appointment to meet with CES faculty to address how the technology assessment mechanism applies to their specific capstone project. Student performance with respect to this application counts for 10% of the final grade for each of the capstone design teams. These arrangements provide us with meaningful participation in technical design courses, incentivize students to take real-time technology assessment seriously, and provides a structure for integrating STS content into the engineering curriculum.

The development of the RTTA model demonstrates the ways that we, as social scientists who study engineering, we are distinctively well positioned to provide robust pedagogical devices that are informed by contemporary social scientific approaches to the study of science and technology. This project also positions members of our department with a unique vantage point from which to add to the social scientific literature on best practices for "upstream engagement" with emerging technologies. This literature examines how social and ethical considerations may be introduced into early phases of the development of new technologies. Our pedagogy allows us to add to this literature by looking at how the competencies required for engineers to be able to engage in these activities might be best taught.

Another example of how we can take advantage of our unique positioning is the pedagogical approach we have developed to the concept of responsible research and innovation (RRI), which has garnered a great deal of attention in STS, though not much has been done to conceptualize RRI as pedagogy. Responsible innovation is a conceptual framework developed by scholars from Science and Technology Studies (STS) and technology policy to bring societal values to the forefront of the innovation process, as opposed to more traditional models of innovation that do not problematize the connection between innovation and societal benefits, and focus more narrowly on economic benefits (Grunwald, 2011; Stilgoe et al., 2013).

The approach we have developed for integrating RRI into the engineering curriculum is another example of RTTA, in this case operationalizing the insights from the constructive technology assessment literature (Franks, 2012; Genus, 2006; Rip, 2008). It calls for social science research agendas that 1) anticipate plausible future sociotechnical scenarios connected to emerging technologies, 2) engage publics and stakeholders about these scenarios, and 3) integrate the results of these into the innovation process to align the innovation trajectory more closely with societal values. This three-part research agenda forms the basis of our pedagogical approach and will further our understanding of how a robust technology assessment approach can be incorporated into the classroom in engineering design courses.

DEPARTMENT OF ENGINEERING AND SOCIETY, UNIVERSITY OF VIRGINIA

History

Embedded STS has a longer history at the University of Virginia than at Concordia University. The University of Virginia opened its doors on 7 March 1825. From the first day of classes, engineering education was an integral part of the curriculum, but it was not until 1836 that University of Virginia established a formal School of Civil Engineering. By 1904 the number of engineering disciplines represented had expanded, and William M. Thornton was named Dean of Engineering. Many details of the current engineering curriculum trace back to Dean Thornton's tenure, including the requirement of a graduating thesis. Thornton believed in the importance of bringing liberal arts instruction within the school of engineering itself. The University Catalogue of 1904-1905 describes Thornton's original graduating thesis:

> Every candidate for a degree in Engineering will be required at the beginning of his graduating year to submit to the Dean some subject for independent study suited to the student's especial course and aims. After such subject has been approved by the Dean and the Professor in charge, the student will be expected to carry out for himself the necessary literary and laboratory researches and to present his results in the form of a Graduating Thesis. Such thesis must be typewritten on standard sheets, 8 by 10 ½ inches, bound in a proper cover, and handed in for final approval no later than May 25. All necessary computations and drawings must accompany the thesis. Serious weight will be given to this work in estimating the student's fitness for graduation. [8], pp. 226-227.

Dean Thornton elected Joseph Lee Vaughan as the first professor of humanities for the School of Engineering. In the 1930s, Vaughan established the Division of Engineering English. The University of Virginia was not alone among engineering schools in incorporating nontechnical units; the engineering colleges at the University of Michigan and the University of Wisconsin introduced similar programs. The University of Virginia, however, was innovative in the way it expanded its vision for the program. In the 1960s, the program encompassed the engineering humanities, and in the 1990s the program aligned with the newly emerging field of STS. The program was known successively as the Division of Humanities, then the Division of Technology, Culture, and Communication. In 2007, the program reorganized as the Department of Science, Technology, and Society, joining a growing community of STS programs nationally and internationally. In 2012, in yet another reorganization—and in a process analogous to earlier incarnations of the CES—the STS Department incorporated faculty in applied mathematics and other domains common to all engineering majors and became the Department of Engineering and Society. While the current thesis project takes a different form from the one instituted in the early 1900s, the origins of the Science, Technology, and Society (STS) program trace back to Thornton's original graduating thesis, now known as the undergraduate research portfolio. It is also worth noting that the historical development of the program, although distinctive in many ways, reflected broader trends in engineering education nationally.

Mission and Approaches

The mission of the School of Engineering and Applied Science at the University of Virginia "is to make the world a better place by creating and disseminating knowledge and by preparing engineering leaders to solve global challenges" [9]. The STS program plays an essential role in achieving this mission by preparing students with four required courses that address the dynamic interplay of technology and society. The curriculum centers on the concept that engineering involves the integration of both technical and social factors.

As students progress through the engineering program at the University of Virginia, they are required to take four STS courses. Students take the first required course, *STS 1500: Great Inventions that Changed the World*, during their first year at the university. This course familiarizes students with the engineering profession, engineering ethics, and the social issues of professional engineering practice. At the same time, this course strengthens writing and speaking skills while highlighting the challenges of professional communication in engineering and applied science.

Students take the second required course during their second or third year in the program. These *STS 2000*- and/or *STS 3000*-level courses play a pivotal role in providing students with an immersive experience to further examine the social and ethical issues of science and technology. Each course has a particular focus, such as the evolution of the iPhone or Thomas Jefferson's interests in science and technology. Courses explore these specific topics through categories of science and technology in social and global contexts, or through the lens of science and technology public policy. This second required course improves students' grasp of how contextual factors shape science and technology. Students are free to select the topic of their choosing, and offerings vary depending on professors' disciplinary expertise.

To continue Dean Thornton's vision of an undergraduate thesis, the third and fourth courses are dedicated to creating a prospectus and writing an STS research paper that is included in the undergraduate portfolio. The third required course is *STS 4500: STS and Engineering*

Practice, which offers a broad overview of concepts in the field of STS and requires that students compose a thesis prospectus, a document that articulates their approach to resolving a sociotechnical problem related to their engineering field. The fourth and final required course is *STS 4600: The Engineer, Ethics, & Professional Responsibility*, which focuses on case studies of engineering ethics, technological leadership, and adaptive problem solving. In addition to examining the social role of the engineer in modern society, students complete their undergraduate thesis portfolio, a full examination of the technical and social dimensions of a relevant engineering problem. Included in this portfolio are a sociotechnical synthesis, a technical report, an STS research paper, and a prospectus. All completed portfolios are permanently cataloged and stored in the Science and Engineering Library. The overall goal in this four-course sequence is to optimize the contributions of the humanities and social sciences generally, and STS in particular, to an integrated understanding of the sociotechnical systems that practicing engineers help create and manage.

Accreditation

The STS program at the University of Virginia satisfies the requirements of the Accreditation Board for Engineering Technology (ABET), the American counterpart of the Canadian Engineering Accreditation Board. Unlike other United States STS programs typically located in colleges of arts and sciences—but like the program offered by CES—the University of Virginia's STS program focuses on the ways a sociotechnical perspective provides a more robust and practical understanding of the nontechnical (also called "professional") competencies that are essential to successful engineering practice. Because STS is an interdisciplinary field, STS courses are intrinsically integrative and allow the school to provide efficient instruction.

At the time of our most recent accreditation visit in 2016, ABET required that engineering degree programs demonstrate that students are competent with respect to 11 educational outcomes, only three of which are not developed or assessed in STS courses: (a) an ability to apply knowledge of mathematics, science, and engineering, (b) an ability to design and conduct experiments, as well as to analyze and interpret data, and (c) an ability to design a system, component, or process to meet desired needs. Outcomes d-j, listed in Figure 2 below, are developed and assessed in STS courses. The students are also required to complete a major design experience. As is the case at Concordia University, some of the outcomes are, for assessment purposes, the sole responsibility of the STS courses. In other cases, the outcomes are developed and assessed in both STS and courses in the student's major.

ABET Criterion 3 Outcomes and Assessment *Only those developed and measured in STS courses are included. The description of each outcome as provided by ABET appears in bold type. The elaboration that follows captures our interpretation of the outcome for the purposes of our courses.*
(d) **an ability to function on multi-disciplinary teams**: appreciate perspectives that differ from your own and integrate your individual expertise and views with those of other people of both technical and non-technical backgrounds
(e) **an ability to identify, formulate, and solve engineering problems**: identify, formulate, articulate, and solve engineering problems; think critically about and reflect on the processes of problem definition, engineering design, and project management
(f) **an understanding of professional and ethical responsibility**: understand professional and ethical responsibilities as they apply to both particular engineering projects and to the engineering profession as a whole
(g) **an ability to communicate effectively** with both expert and non-expert audiences
(h) **the broad education necessary to understand the impact of engineering solutions in a global and societal context:** understand the impact of engineering solutions in a global and social context and use that understanding in the formulation of engineering problems, solutions, and designs
(i) **a recognition of the need for, and ability to, engage in lifelong learning:** the development of the research and analytical skills necessary to engage in lifelong learning and understand why it is necessary
(j) **a knowledge of contemporary issues**: recognize and analyze the role that technology and engineering play in important contemporary issues and use a knowledge of social and historical context to put contemporary issues in perspective
ABET Criterion 4 Outcomes and Assessment **As part of the major design experience, consider and integrate economic, sustainability, ethical, political, health and safety and sociopolitical issues into the design, implementation, and management of technological systems**: systematically explore the full range of non-technical issues that are part of the problem addressed by the project and might arise in the design, implementation, and management of technological systems that make up the context of the project; include the relevant non-technical issues in the problem as it is defined in the Thesis Project Prospectus; explore at least one important issue in depth in the STS Research Paper; and articulate the relationship between the STS research and the technical deliverable in the sociotechnical synthesis that is included in the thesis project portfolio.

Figure 2: 11 Professional Areas for ABET Accreditation [10]

During the school's most recent accreditation, the Engineering Accreditation Commission of ABET took special note of the STS curriculum's effectiveness in covering the required outcomes. In its 2017 report to the university, the commission singled out the STS program as one of the school's institutional strengths and recognized it for its leadership:

> The set of science, technology, and society courses that *all engineering students take* [emphasis added] provides excellent coverage of several student outcomes which are historically among the most difficult for programs to cover. For example, the coverage of ethics issues has recently been recognized by the National Academy of Engineering. This approach to coverage of the several student outcomes is a best practice from which other programs can learn [11].

The research introduced in this paper is intended as a step toward translating the features of the embedded approach exemplified by both programs described in this paper into a flexible set of transferable practices that could be successfully adopted and adapted by other schools and faculties of engineering.

DISCUSSION: Defining, Justifying, and Living STS for Engineers

As a first approximation at delineating the fundamental tasks of embedded STS programs, we propose the categories defining, justifying, and living STS for engineers. Defining STS for engineers requires us to ask this question: What are our approaches and overall goals? Justifying STS for engineers suggests another question: How do we make an argument for the importance of embedded STS to accreditation boards, universities, and engineering administration? Living STS for engineers entails asking a very different question that is even more multifaceted than the others: What is it like for faculty to work in an embedded STS environment?

Defining: Course Structure and Content

Although the programs of Concordia University and the University of Virginia differ significantly in the length of their history, they both illustrate the ways embedded STS programs are distinctively positioned to support the technical training of engineering students. The shift that both programs have experienced (or are experiencing) illustrates the ways in which technical programs can come to perceive STS training as integral to creating well-rounded engineers. They also share several common features.

While the two programs at Concordia University and the University of Virginia require a different number of courses for graduation, they exhibit many overlapping features unique to embedded STS programs, e.g., the emphasis on sociotechnical connections. Course syllabi from both institutions highlight the idea of complex relationships between technology and society, an important feature of embedded STS programs due to the varieties of examples students discuss and debate.

The capstone project experience presents another similarity between these two unique embedded programs: both universities require a year-long technical capstone project before graduation that incorporates STS into the process, albeit in different ways. Concordia University incorporates sociotechnical thinking into the engineering design process of capstone project teams by asking what value decisions are being made, and what choices have to be reevaluated along the way? The University of Virginia requires students to explore the perspectives and interests of multiple stakeholders as the define the problem their technical work is designed to solve and then asks them to pursue a non-technical dimension of the problem or the implementation of the solution in depth in a separate STS research paper. Both approaches are designed to ensure that the capstone project considers multiple stakeholders and suggests that STS is widely applicable to the overall engineering design process. Some STS research papers align more with the technical capstone project topic than others, but the understanding reached through the STS research often enhances the capstone project, just as the technical project often grounds the STS research in the real world of ongoing problem definition and solution. The strategies of both programs give students the opportunity to critically examine engineering problems through the illuminating lens provided by STS. What both approaches accomplish is teaching engineering students that engineering projects rarely (if ever) have predetermined solutions, necessary ultimate outcomes, or implications for the most prominently articulated values that serve as the explicit motivation for the project. These moments of critical reflection form central components of embedded STS programs. The skills acquired through STS courses enhance, rather than distract from, technical training.

Embedded STS programs can also bridge the gaps between technical training and the application of that training in business and entrepreneurial ventures by tracing the sequence of cause and effect by which innovation translates into actions with social and ethical significance. A recent article titled "The Ethical Dilemma Facing Silicon Valley's Next Generation," by Victor Luckerson, demonstrates the significance of such gaps by reporting on a talk given at Stanford about the company Theranos, a blood testing company that falsified lab results, ultimately putting patients at risk. Students did not hear from the founder of the now dissolved company, but rather from the whistleblowers Tyler Shultz and Erika Cheung. Both Shultz and Cheung made powerful statements about the uncertainty and risk of handling new technologies, or the consequences these new technologies have [12]. While this talk mainly targeted Stanford students, it contains important lessons about university leadership and the role engineering educators should play in preparing students for responsible innovation by showing them the many ways in which ethical and social considerations are built into technical advancements as they become the basis of entrepreneurial ventures or domains of practice in which human welfare is at stake. Neither the stated missions of the institutions that educate engineers nor the companies who hire them can be achieved without greater integration of ethical and social considerations within a technical field. Embedded STS programs can achieve this integration without reinventing the entirety of the engineering curriculum or downplaying the necessity and importance of technical training.

Justifying: Licensure and Accreditation

Two of the primary ways to understand the social and ethical components of engineering are licensure and accreditation. "Licensure is the mark of a professional. It's a standard recognized by employers and their clients, by governments and by the public as an assurance of dedication, skill and quality" [13]. Social and ethical components reveal themselves in this arena through professional codes of ethics. The primary professional obligation of the engineer, familiar to every professional engineer in both Canada and the United States, is to "hold paramount the safety, health, and welfare of the public" [14]. The accreditation standards of engineering programs across North America enforce this competency, nominally required for any engineer. While at first glance the two accrediting bodies (ABET in the U.S. and CEAB in Canada) seem to have similar standards, important differences exist in the contexts in which each sees the role of social and ethical professional competencies.

Two differences in particular are worth noting. First, the professional systems in which licensure and accreditation take place for engineering in the U.S. and Canada differ greatly. The Canadian professional system is a closed system, reserving both right to title and right to practice to professional engineers. A person cannot use the title "engineer" or legally perform an act deemed to be an act of engineering if they are not a member in good standing of one of the provincial professional engineering orders. The professional system in the U.S. (in so far as there is anything that could be called a "system" at all) looks radically different. Only about 20% of engineers are "professional" engineers in the U.S., since becoming one is not a requirement. While the title of "professional engineer" is reserved to those who are properly licensed (a process that varies from state to state), engineering acts are not reserved at all. Anyone can practice [15].

Second, different relationships between licensure and accreditation in the U.S. and Canada create serious differences in how universities treat social and ethical competencies. In the U.S., licensure bodies are independent of the accreditation board. While conversations across licensing bodies (the National Society for Professional Engineers (NSPE) and ABET) take place, often during American Society for Engineering Education (ASEE) meetings, no formal relationship exists between the two areas. In Canada, licensing bodies (the professional orders in each province) and the accreditation body (CEAB) are formally and legally coupled through the national organization Engineers Canada [16].

The authors have argued elsewhere [17] that the closed professional system in Canada, which requires the coupling of the licensure and accreditation processes, provides engineering educators with greater opportunities to introduce robust methods for teaching professional competencies around the social and ethical nature of engineering practice. Given that the same body oversees the standards for education and licensure, Canadian engineering educators must take each of the graduate attributes seriously [18]. This professional-educational bond, along with the fact that all engineers must go through the licensure process, creates an environment in which the CEAB outcomes-based assessment process is treated more seriously than the similar outcomes-based assessment process required by ABET.

Differences in accreditation processes and licensure between the United States and Canada are undoubtedly important, but the difference in engineering culture may be even more important. Exemplified in the Ritual of the Calling of the Engineer, created by Nobel Prize winning author Rudyard Kipling at the request of seven previous presidents of the Engineering Institute of Canada and first performed in Montreal in 1925. Called "The Iron Ring Ritual," it includes an oath analogous to the Hippocratic Oath in which newly graduated engineers promise not to "suffer or pass, or be privy to the passing of, bad workmanship or faulty material in aught that concerns my works before mankind as an engineer" [19], p. 32. and receive a rough-hewn iron ring "worn on the pinky finger of the dominant hand, a tactile symbol of an engineer's responsibility to the profession" [19], p. 32.

As the article on the ritual in *Prism* reports, "more than 200,000 people have participated in the Ritual of the Calling of the Engineer, and currently 15,000 are added to the list every year" [19], p. 32. These numbers are even more remarkable given that participation in the ritual is, like the Hippocratic Oath, voluntary. One engineer who participated in the ceremony described it as "a form of contrition for the rivalry and errors that had results in engineering debacles such as the Quebec Bridge Disaster. The ceremony is more of a pledge to work honorably and faithfully before other engineers—their peers—rather than the public in general. That probably explains why only engineers are present in many places" [19], p. 33. Although there are some American engineering graduates who participate in this ritual, nothing like it, or the organizations that promote it, exists in the United States. The history and existence of the ritual suggest a much stronger professional identity for engineers as a group distinct from the corporations and agencies for whom they work.

Living: Faculty Experiences of Enacting an Engineering Studies Approach

The most important difference for STS scholars embracing an engineering studies approach is that they address engineering students, practitioners, and faculty in addition to other STS scholars. Being embedded offers both an enhanced opportunity for observing and describing the culture of engineering and an organizational location that provides more opportunities than we would have otherwise to communicate with engineering students and faculty. As Gary Downey describes it,

> scholars [engaged in engineering studies scholarship] not only conduct research on engineers and engineering but also design and teach courses for engineering students, serve on official panels and advisory committees, offer presentations to engineering audiences, and help build a new discipline focused on engineering education [they also] venture beyond research for STS audiences and pedagogical supplements in the curricular margins to begin contesting the dominant epistemological practices by integration practices of critical self-analysis in the core of engineering curricula [20], p. 55.

One way to look at the emergence of engineering studies as a distinct area of scholarship is that it was a culmination of the attempts at integration and what might be called "applied STS" in the wake of the implementation of the EC 2000 accreditation criteria in the United States, "calling attention to relationships, both actual and potential, between scholarly practices in engineering studies and the dominant existing practices of engineers and engineering" [20], p. 57.

Downey sees his articulation of engineering studies as a response to "the relative invisibility of engineers and engineering in STS research" [20], p. 58 guided by the precedent set by Antonio Gramsci's attempt to discern "the pathways through which philosophical interpretations might escape cloistered abstraction to become historical realities, extend influence beyond individual creators, and gain the authority of 'life'" [20], p. 64. For Downey, the main strategy is to define engineering as collaborative problem definition and solution, emphasizing collaborating with stakeholders who define problems differently than engineers do. Faculty in embedded programs bring engineering students into direct interaction with those differing perspectives and can help them see how different perspectives both diminish the chances of adverse social outcomes and contribute to the development of more robust sociotechnical solutions to problems.

As has been the case quite recently in Canada, for those who were involved in the non-technical dimensions of engineering education in the United States, the EC2000 outcomes presented an opportunity and an incentive to document our contributions, and the hope of having those contributions valued and validated by faculty in the various engineering degree programs. The outcomes STS courses develop and assess are more numerous than those developed through the STEM components of degree programs, and courses in integrated, interdisciplinary programs like those described in this paper can be both innovative and efficient in achieving the non-technical outcomes. Developing documentation for the accreditation process offers an opportunity to make the contributions of STS visible to the full range of degree programs, or at least to the faculty responsible for preparing the self-study that precedes each accreditation visit. Designing the courses and curricula that help students achieve those outcomes provides an opportunity to demonstrate the value of STS perspectives to engineering practice.

The period leading up to the implementation of the EC2000 saw a burst of creative activity aimed at realizing the integrated vision that STS scholars saw implicit in the new criteria. As faculty and administrators grappled with the challenges of finding a place for integrative educational experiences in engineering curricula, they often benefited from funding available through the National Science Foundation and other sources for improving engineering education. Although early assessments of the impact of EC2000 suggested that it had spurred curricular innovation, one of its primary aims, the full potential of the integrated approach has not been realized for reasons that are primarily structural, but also cultural.

The most significant structural factor stems from the fact that ABET accredits degree programs rather than institutions. This makes the degree programs, usually co-extensive with department structures, the primary unit of planning, instruction, and assessment. In the United States, the accreditation evaluators are recruited and trained through the various engineering professional societies. Although these societies do not have the legal standing of their counterparts in the Canadian system, they provide a crucial link between the world of engineering practice, including the organizations that hire engineers, and play a gatekeeping role in the accreditation process. Because the accreditation teams consist of one representative from each of the professional societies associated with the degree programs at the institution being evaluated, there is no formal role for people with STS expertise in the accreditation process, and no mechanism for consistently or comprehensively acquainting the disciplinary visitors with state-of-the-art approaches to integrating STS perspectives into engineering education. The lesson that seems to have emerged from over 20 years of implementing the outcomes-based accreditation process that emphasizes non-technical abilities is that changing the criteria has minimal impact, but you do not also change the assumptions, knowledge, and values of the individuals who actually execute the assessment process. For the reasons documented in this paper, STS faculty embedded in engineering programs are well-positioned intellectually and organizationally to assist in the integration process, but their position outside of the individual programs being accredited can significantly limit their impact. One hope of the research introduced here is that understanding the ways engineering education in the United States has resisted the integrative approach inherent in the inclusion of professional (non-technical) outcomes in the required competencies of engineering graduates, can shape the evolution of the Canadian response in a different direction.

CONCLUSION

The information and analysis presented in this paper shows the way that two embedded STS programs with different histories and geographical locations present a distinctively strong model for addressing societal and ethical implication of engineering practice in engineering education. We are both housed within a faculty or school of engineering and computer science. The curricula that we design and teach allow us to apply and also require us to move beyond our graduate training. That expansion of expertise and view puts us in an excellent position to be mediators between engineering/computer science and the rest of our universities—and also within interdisciplinary collaborations in engineering. We are social scientists embedded within the culture of engineering education that we wish to study. However, we are not engineers. We are social scientists (philosophers, rhetoricians, anthropologists, sociologists, and humanists) who study and teach about the social, ethical, and legal implications of engineering practice. Broadened accreditation requirements, combined with increased awareness of social-technical interactions and the sense of urgency created by ethical lapses in entrepreneurship, provide an environment in which we can be recognized as collaborators in the common enterprise of engineering education rather than marginalized service providers to an enterprise in which we in which we supply the engineering faculty with "soft" or "complementary" courses seen as a supplement to an otherwise purely technical curriculum. These forces can create a new ecosystem view of engineering education in which embedded STS faculty can constructively and creatively shape engineering curricula without causing them to be completely redesigned.

Our research and analysis have also illustrated numerous difficulties and hazards of embracing an embedded model of STS in engineering education. In many cases these liabilities seem inextricably entwined with the advantages of being embedded. One of the most significant challenges is that the descriptor "embedded" seems to describe a continuum more than a category. Another is the embedded is the antithesis or antidote to the loaded by ill-defined concept of a "service" department. The work described here has yielded three emerging features that distinguish the departments we call embedded from "service" departments: (1) the opportunity to formulate our own curricular goals and pedagogical strategies that ultimately change the character and quality of the educational experience of the engineering students we teach; (2) full participation in the governance and administration of the faculties and institutions of which we are a part; and (3) pursuing our own research agendas in addition to engaging in interdisciplinary research and outreach efforts.

The initial evidence suggests that there is no standard definition of embeddedness, but rather distinctively strong approaches in accomplishing interdisciplinary models. In future work, the research team plans to reach out to other STS professionals who might consider themselves embedded with the goals of creating a preliminary typology of embedded STS programs, exploring the range of meanings of the term "embedded," and finding commonalities in the courses offered in and other features of embedded programs.

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