Applying STS to Engineering Education: A Comparative Study of STS Minors

Prof. MC Forelle, University of Virginia

MC Forelle is an assistant professor, teaching track, in Engineering & Society at the University of Virginia School of Engineering and Applied Science. Their work examines the intersection of law, technology, and culture, with particular interests in materiality, sustainability, and practices of resistance and change. Currently, they are developing a a book project that studies the technological challenges faced by users, tinkerers, and repair communities working to repair, maintain, and modify software-enabled automotive technologies, and the various legal avenues they are pursuing to resist corporate control over their devices.

Mr. Kent A. Wayland, University of Virginia

Kent earned his PhD in Anthropology at the University of Virginia and is now a Lecturer in the Department of Engineering and Society, School of Engineering and Applied Science, at the University of Virginia

Dr. Bryn Elizabeth Seabrook, University of Virginia

Bryn Seabrook is an Assistant Professor in Science, Technology, and Society at the University of Virginia. She received her Bachelor of Arts in Humanities, Science and Environment with a minor in Vocal Performance in 2012, a Master of Science and Technolo

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MC Forelle, Kent Wayland, and Bryn Seabrook
University of Virginia/University of Virginia/University of Virginia

Abstract

In recent years, the field of Science and Technology Studies (STS) has seen tremendous growth in universities across the United States. A subset of these new STS programs are being integrated in engineering and other STEM-focused institutions, frequently in the form of STS minors. The purpose of this study is to expand on previous work by Neeley, Wiley, and Seabrook (2019), who in "In Search of Integration: Mapping Conceptual Efforts to Apply STS to Engineering Education," argue that the critical skills that STS offers are essential for helping engineering students understand the impact of technological innovation in a holistic sense. An STS minor has the additional advantage of providing students with a recognized credential in this skill set. Thus, in this paper, we ask further: how are STS minors being designed to provide this critical education as well as attract student attention and fulfill the mission of the school? The authors address this question through a qualitative analysis of outward facing material of minors offered through top engineering institutions. Our goal is to understand the state of current practice, and to build toward recommendations to making STS a valuable complement to an engineering education.

Keywords

Undergraduate Education
Curriculum Design
Minor Programs
STS

Introduction

There is no standard for incorporating nontechnical engineering skills in undergraduate curricula. While this lack of standardization is not necessarily a problem, as each institution has its own programs and interests, engineering educators should seek to learn from the variety of ways that these skills are embedded into the curriculum. One field specifically dedicated to exploring the nontechnical aspects of engineering is Science and Technology Studies (STS), which in recent years has seen tremendous growth in universities across the United States. Much of this growth comes through the introduction of STS departments and programs into liberal arts schools or divisions. However, a subset of these new STS programs is being integrated into engineering and other STEM-focused institutions. According to David Hess, the field of STS "provides a conceptual toolkit for thinking about technical expertise in more sophisticated ways."[1] However, there are as yet no established conventions for how these skills should be delivered. As Seabrook et al describe in *Teaching STS to Engineers: A Comparative Study of Embedded STS Programs*, "Some programs feature standalone courses from outside the engineering school. Others incorporate STS material into traditional engineering courses, e.g., by making ethical or societal impact assessments part of a capstone project."[2] While the interdisciplinary nature of STS makes it difficult to define, the foundational concepts draw on related fields such as philosophy, sociology, anthropology, history, cultural studies, and feminist studies. Bringing this interdisciplinary approach to educating engineering students allows them to approach their profession in ways that enhance their problem-solving skills and professional communication skills. Given these benefits, the problem engineering programs face is how to integrate these skills within the curriculum as opposed to outsourcing these course offerings to other parts of the university.

Reflecting on the 1955 Grinter Report, Sheryl Sorby, Norman L. Fortenberry, and Gary Bertoline suggest a need for a revolution in engineering education, writing:

> "Over the years, we educators have done some tinkering around the edges, such as adding in a capstone design project, or replacing Fortran with other programming languages – but the basic structure of the curriculum remains unchanged even though our students can now find information on their phones that might have taken us hours to track down in the library."[3]

There is no doubt about the need for technical training, but how engineering educators incorporate nontechnical skills also has an impact on creating a well-rounded engineer. *The Engineer of 2020: Visions of Engineering in the New Century* challenges educators to reimagine, redesign, and reevaluate what engineering education should look like given the questions raised by emerging technologies.[4] One of the ways in which educators can incorporate nontechnical skills is through encouraging minors that enhance technical training through an emphasis on critical thinking and analytical skills. The purpose of this study is to examine minor offerings embedded within top engineering programs in the United States that attend to or enhance these nontechnical skills.

Background

The American Society for Engineering Education (ASEE) proceedings include a breadth of publications, particularly in the context of implementing teaching strategies that prepare the engineer of the future. As Herkert remarks,

> "MIT's first Dean for Undergraduate Education, the late Margaret MacVicar, once noted [in 1987] that the challenge for educators with respect to integration of engineering, humanities and social sciences is to bring about: '…a true educational partnership among the technical, arts, social and humanistic disciplines so that on some level students see the interrelationships between science and technology on the one hand, and societal, political, and ethical forces on the other.'"[5,6]

Engineering is not separate from sociotechnical issues, but rather has to be understood as deeply intertwined with them. This intertwining is the central tenet of the field of science and technology studies (STS), motivating both research and teaching. As a discipline, STS is fairly new, tracing its roots to the 1980s, but as it has grown, it has taken up MacVicar's challenge to partner with engineering programs to integrate the humanities and social sciences into engineering education.

The first publication within ASEE that specifically attends to integrating STS within engineering education is a paper presented at the 1997 annual conference titled *STS for Engineers: Integrating Engineering Humanities and Social Sciences.* In it the author describes efforts to define STS as a general education requirement at North Carolina State University, specifically mentioning the opportunity and justification for a minor in STS. However, it is not until the later 2000s that scholars began discussing models of integration between engineering education and STS in formal engineering curricula.

The ASEE proceedings suggest an inquisitive mindset about how STS can help develop the sociotechnical skills of engineering, but there is a need for greater investigation into how to implement these emerging models. In their analysis of the alignment between engineering schools' stated aspirations and the enactment of those aspirations in their curricula, Neeley, Zajec, and Stup conclude that:

> While the engineering achievements and their positive impact are well-established, it is not at all clear that engineering curricula *systematically* prepare graduates to develop and manage 'complex technologies and products,' 'contribute directly to the betterment of humanity,' or avoid unintended 'negative results of technology [such as] pollution, global warming, depletion of scarce resources, and catastrophic failures of poorly designed engineering.'[7,8]

This gap noted by Neeley et al. echoes MacVicar's goal of cultivating engineers' ability to examine the "interrelationships between science and technology on the one hand, and societal, political, and ethical forces on the other."[9] Integrating STS into the undergraduate engineering curriculum, therefore, could be a pathway to cultivating that ability. This integration presents a challenge, however. One approach to the challenge has been to create a minor that complements the technical skills of an engineering major.

Research on the impact of minor programs on student learning and employment opportunities is relatively underdeveloped, especially within ASEE. One exploratory project has been published on the possible benefits of increasing the number of social work minors offered across the country.[10] In it, the author identifies a number of advantages to offering more social work minors, which we highlight here due to the compelling parallels with the development of an STS minor within a college of engineering:

1. *Social services are increasingly being provided in interdisciplinary environments* - The parallels here with engineering occur frequently in computer engineering and computer science, where computational approaches to problem-solving are being applied in increasingly varied contexts.
2. *Social work minors may attract greater diversity to the social service work force and the social work profession* – The University of Virginia states that there are "approximately 34% women among our undergrads, compared to the national average of 21%."[11] As a field, engineering has not reached gender parity, let alone equity in the representation of historically marginalized groups.

3. *Increasing the number of students in the social work program may have practical benefits for the university and the department* – Some practical benefits of encouraging nontechnical skills include a greater understanding of the influence of science and technology, ability to respond critically to sociotechnical issues, and understanding the greater interactions between science, technology, and ethics.

In further support of point number 2 - that minor programs can attract greater diversity to a field - other scholars have also noted that minors can be a powerful way to create spaces where minoritized students can feel like their concerns and experiences are valued.[12] Goodstein and Gyant add that this serves faculty as well as students, as minor programs can be a route for creating permanent curricular offerings in certain topics.

Most existing literature on academic minors examines minor programs that exist within departments that offer that field of study as a major; thus, these minors are frequently designed as either majors-in-miniature or as an exploration of topics covered by the major.[13] What is missing in the literature is a consideration not only of the content and design of a minor, but how that content and design coincide with the institutional home of a minor. Thus, our work contributes at two levels: first, as an analysis of the STS minor as a category; and second, as an analysis of a non-engineering minor housed specifically within a school of engineering. We propose that engineering programs enhance and support minors that cultivate STS-style critical thinking about the interrelationships of technology and society.

Methods

Echoing previous work on the content and design of minor offerings,[14] we chose to focus on curriculum materials available on university websites. These are the materials that undergraduates researching minor offerings are most likely to be engaging with; given our interest in understanding how these programs are marketing themselves to possible enrollees, then, focusing on these sources seemed most appropriate. However, we recognize that relying on these materials comes with certain disadvantages. As Neeley, Zajec, and Stup detailed[15], websites as a source of evidence for curricular practices present the following limitations:

1. The difficulty of representing the intellectual rationale and course content in that format;
2. The lack of consistency in website organization and design;
3. The tremendous amounts of path-dependent detail that are inherent to engineer programs of study;
4. The challenges of keeping website content up to date; and,
5. The reality that website design has become a public relations activity to a much greater extent than hard copy course catalogs were in the past (p. 5)

While we acknowledge these limitations, we find that the outward-facing language of minor programs provides a rich resource to gain a better understanding of how engineering programs are supporting and integrating STS skills at an undergraduate level.

In determining which engineering schools' minor offerings to examine, we did diverge from previous work. Rather than focusing on the top-ranked engineering schools, as Neeley, Zajec, and Stup did[16], we instead elected to examine the engineering schools producing the highest number of undergraduates, using the numbers reported in the ASEE's annual reports.[17] In taking this approach, we were curious to see what we would find from the highest volume, instead of the highest ranked, schools, to see how this larger number of students is served. We asked each group member to explore the offerings of seven schools, for a total of 21 institutions. We list the schools, and the number of graduates they each produced in the year 2021, below:

Institutions Awarding the Highest Number of Engineering Bachelor's Degrees

1. Georgia Institute of Technology - 2,765
2. Purdue University - 2,479
3. University of Illinois Urbana-Champaign - 2,465
4. Texas A&M University - 2,375
5. University of Michigan - 2,316
6. Arizona State University - 2,304
7. University of California, Irvine - 2,138
8. The Pennsylvania State University - 2,037
9. Virginia Polytechnic Institute and State University - 2,013
10. University of Central Florida - 1,926
11. The Ohio State University - 1,855
12. Iowa State University - 1,845
13. University of California, Berkeley - 1,839
14. University of Maryland, College Park - 1,799
15. University of Florida - 1,765
16. The University of Texas at Austin - 1,751
17. Oregon State University - 1,695
18. University of Wisconsin-Madison - 1,687
19. North Carolina State University - 1,678
20. University of California, San Diego - 1,645
21. Rutgers, The State University of New Jersey, School of Engineering - 1,522

Of these, we identified which schools offered minor programs that either explicitly taught STS, or taught STS-adjacent theories or concepts. To develop our list of STS-adjacent theories and concepts, we employed a form of conventional content analysis.[18] Each researcher read through the general description of each minor offered by their set of schools, searching for any clear references to: humanities or social-scientific disciplines; such nontechnical topics as policy, humanitarianism, and ethics; or anything that we classified as STS-like thinking because it involved critical thinking about technology and society. After we had identified the minor programs we felt could fit these categories, we met to compare our findings and to agree on the range of minors that we would consider. We then collected all materials available online for these minor programs, including: the language by which they were described on department or school websites; information from the registrar's site; and any additional promotional language through related programs' websites.

After an initial read-through of the collected materials, the team gathered to discuss the themes and terms that appeared frequently across minors and that also indicated a focus on sociotechnical topics or concepts related to STS. We used these themes to establish the coding schema for our next read-through of the materials. To apply this schema, each researcher took a set of codes and worked through all of the available materials. (In other words, we divided by code instead of dividing by school, as in our initial read-through to identify the minors.) After applying our individual codes, we met again to talk through and compare our coding and to develop our analysis, the details of which follow.

Results

Table 1. List of STS and STS-adjacent minors offered within the schools in our study.

University	School	Title of Minor	Credit hours
Georgia Institute of Technology	College of Engineering	Global Engineering	15
University of Illinois Urbana-Champaign	The Grainger College of Engineering	International Engineering	21
Texas A&M University	College of Engineering	Cybersecurity	16
University of Michigan	College of Engineering	Environmental Engineering	16
		International Minor for Engineers	15
Arizona State University	Ira A. Fulton Schools of Engineering	Human Systems Engineering	21
		Environmental and Resource Management	18
Virginia Polytechnic Institute and State University	College of Engineering	Green Engineering	18
		Human-Computer Interaction	18
The Ohio State University	College of Engineering	Science, Engineering, and Public Policy (*offered through the John Glenn College of Public Affairs, but advertised on the College of Engineering website alongside endemic minors*)	12-13
		Humanitarian Engineering	15

University of Maryland, College Park	A. James Clark School of Engineering	Science, Technology, Ethics, and Policy (*interdisciplinary minor with School of Public Policy and College of Information Studies*)	15
		Global Engineering Leadership	16
Oregon State University	College of Engineering	Humanitarian Engineering	27
		International Engineering	30-48

As described in Table 1 above, we conducted a conventional content analysis of the collected descriptions of the minors and their requirements. The coding schema included the following terms:

- Ethics
- Social engagement
- Awareness
- Policy
- Humanitarian
- Interdisciplinary/multidisciplinary
- Justice
- Community
- International/intercultural

After each researcher coded all of the collected materials, we met to compare our coding and to look for larger themes and patterns. We did conclude that three terms in our coding schema—"awareness," "community," and "interdisciplinary/multidisciplinary"—did not provide any useful analysis. "Awareness" and "interdisciplinary/multidisciplinary" were generally used in cursory ways as a way of describing a broad attention to something; "awareness of intercultural needs," for example. Consequently, we found both terms to have such superficial applications as to not contribute meaningfully to our analysis. Likewise, with "community," we found its use overlapped almost entirely with either "social engagement" or "international/intercultural," and we therefore removed it as a separate code for analysis. The remaining codes are organized in Table 2 below.

Table 2. Coding schema for minors materials

Keyword	Characteristic marketing language	Sample courses
Ethics	University of Maryland, College Park (UMD) *Science, Technology, Ethics and Policy* • Language of the minor: (Science, Technology, Ethics, and Policy minor)	Texas A&M • *Cybersecurity and Digital Ethics*

	"Students in the minor explore the ways that scientific practice and technological development are embedded in social, cultural, humanistic and political systems."[19]	University of Maryland, College Park • *Introduction to Science, Technology, Ethics, and Policy*
Social engagement	Arizona State University (ASU) *Environmental and resource management* • "provides students with a thorough introduction to environmental regulations and key environmental management issues such as the provision of clean, potable water; wastewater treatment; and solid and hazardous waste management; as well as remediation technologies for polluted soils, groundwater and air. Students learn to apply basic science and engineering principles to solving problems that significantly impact human health and ecosystems."[20] Oregon State University *International engineering* • "The international engineering minor offers undergraduate engineering students an opportunity to certify their global competencies and demonstrate their understanding of the intercultural needs of modern engineers. By combining an engineering experience abroad, courses from a generalized global core, thematic elective courses, and the signature course of the minor, students may demonstrate their readiness for the increasingly global field of engineering."[21]	ASU • *International Environmental Management* • *Environmental Regulations* Oregon State University • *Comparative Cultures* • *Evolution of People, Technology, and Society*
Policy	Ohio State University (OSU) • "success in science and engineering enterprises requires not only a knowledge of technical topics, but also an understanding of the *context* in which science and engineering are undertaken."[22]	OSU • *Science, Engineering, and Public Policy Analysis* • *Contemporary Issues in Science,*

	UMD *Science, Technology, Ethics and Policy* • "Students in the minor explore the ways that scientific practice and technological development are embedded in social, cultural, humanistic and political systems. These connections help students see the variety of ways science and technology can be governed, designed and implemented to optimize the needs of society."[23]	*Engineering, and Technology Policy* UMD (electives) • *Environment, Economics, and Policy* • *Information Ethics and Policy*
Humanitarian	Oregon State University *Humanitarian engineering* • "We define humanitarian engineering as the co-development of science or engineering-based solutions to improve the human condition, namely through improved access to basic human needs, an improved quality of life, or improved level of community resilience."[24] OSU *Humanitarian engineering* • "Humanitarian Engineering is the design and creation of products and processes that promote human welfare, especially for the economically disadvantaged or underserved."[25]	Oregon State University • *Innovation for Social Impact* • *Environmental Justice* OSU • *Computational Humanitarianism*
Justice	OSU *Humanitarian engineering* "Examples of humanitarianism in the engineering enterprise: • Engineers' involvement in creating profit-generating technological products and processes for the poor (related to the debate over "aid vs. trade") while respecting social justice (e.g., via local entrepreneurship/business development)"	OSU • *Crossing Boundaries: A Journey Toward Intellectual Leadership Identity Development*

International/ Intercultural	Georgia Tech *Global Leadership* • "create engineer-leaders who have the technical expertise, global awareness, and leadership skills to address the grand challenges of the 21st century."[26] • "must complete a work, research, study or service-learning experience abroad. This experience gives students an opportunity to exercise **leadership of self** and others in a foreign engineering or technology environment on a real-world problem. Students also develop and apply cross-cultural skills to successfully complete their work." Illinois *International Minor in Engineering* • "With an International Minor in Engineering, you will: Increase your "Global Awareness" and broaden your engineering education; Concentrate coursework in the social sciences and humanities on a particular country or geographical region; Gain a level of expertise in a particular geographical area"[27]	UMD • *Leading Global Teams and Engaging Across Cultures in Business, Engineering, and Technology (DVCC)* • *Teaching and Learning about Cultural Diversity through Intergroup Dialogue*

Discussion

In our analysis of these keywords, we discovered two general purposes toward which STS and STS-related material were applied, which we have distinguished as "engineering *for*" and "engineering *with.*" The distinction between these two purposes is whether the minor seems to be treating sociotechnical considerations as a means to another end—typically employability, product success, or profit generation (engineering *for*)—versus treating sociotechnical considerations as a worthy end in themselves, as a way of understanding the world more holistically and justly (engineering *with*). Or, put another way, is sociotechnical analysis an instrumental tool for achieving other goals, or a goal in itself? Is it inherently a part of engineering, or an add-on skill or certification to make engineers more competitive in the marketplace? Do engineers adopt purely technological solutions, or do they participate in co-defining problems and co-producing answers to those problems, which may de-emphasize technological innovation?

This distinction can be seen in the way different programs described the role of technology, and the engineers' role vis-à-vis technology. Programs that emphasized an "engineering *for*" orientation typically used language that indicated a leaning toward technological solutionism, framing engineering as a way of solving problems, and sociotechnical thinking as a way of developing better solutions.[28] For example, Ohio State University's minor in humanitarian engineering included a description of "justice" that frames justice narrowly, in purely economic terms that imagine redress as inclusion in capitalist development; this stance is further emphasized by the over-representation of economics and political science in the list of approved electives. This was also notable in the way that these minors spoke about social engagement; overall, the language of these minors evinced a keen need to understand non-technical skills, but does seem to come back to the notion that there is a human problem that engineering can "solve."

Conversely, those minors that reflected an "engineering *with*" approach positioned engineering as just one of many skills that were necessary not just for solving problems, but for understanding them in the first place. In this way, these minors communicated both that engineering is itself a deeply cultural practice and that it should also see itself in partnership with social scientific or humanistic approaches to building comprehensive and equitable ways of assessing and addressing issues. Downey[29] made a similar argument when characterizing the importance of integrating international/global education in engineering: that this kind of sociotechnical thinking is not external to engineering, but rather engineering must be seen as inherently sociotechnical, as not being free from subjective, cultural influence–a deeply cultural enterprise.

We see this further in how these programs positioned the engineer's role as a leader or collaborator. Programs with an "engineering *for*" orientation framed leadership and collaboration skills in transactional or extractive terms - that the purpose of learning how to lead or collaborate was to reap the greatest success for your career or your employer. This approach was commonly found in the international or global engineering minors, which emphasized "competency" and "effectiveness" as the goals, which would facilitate successful cross-cultural negotiation or management. On the other hand, leadership or collaboration for "engineering *with*" relied more on language that understood the goal to be co-development and mutuality. For example, where other minors described the goal as solving problems, or even developing solutions, Oregon State University's minor in Humanitarian Engineering puts forward the goal of "*empower[ing]* students to *engage in* solving global development problems" (italics ours). In this way, Oregon State University frames the goal as one of empowerment and engagement, not just problem-solving on its own.

Conclusion

Our analysis not only reveals the differences between approaches to STS-related topics, but also suggests ways that a more deliberate approach to the integration of STS within engineering curricula could expand the horizons of engineering. Going through our gathered materials, we were struck by the repeated references to "humans" and "humanity" with regards to who engineering is for - that engineering should be "human-centered" or executed with the goal of promoting "human well-being." Within STS, there are a number of theoretical threads that challenge a human locus of consideration. Actor-Network Theory, for example, posits that nonhuman actors can act with as much agency and impact as human actors, and must be accounted for in any analysis of the development, implementation, or consequences of a technological system.[30,31] Feminist and indigenous STS scholars have also been calling for more attention to nonhuman, or more-than-human, ways of being, meaning, and mattering.[32,33] How might the focus of engineering pedagogy and practice shift if it could integrate these ways of thinking of and through technical work?

While this study emphasizes the outward facing material of these minors, there are several limitations to this project. Most of the engineering schools that were included in this study have formal STS programs, primarily offered outside of the engineering school in their liberal arts college. This study does not include an analysis of how the existence of these STS programs may have influenced the design of these minors, the decision to offer them in the first place, or the decision to offer these minors over others. Future work indicates the necessity for further analysis about the connection between these formal STS programs and the connection with engineering schools.

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MC Forelle

MC Forelle is an Assistant Professor in the Department of Engineering and Society at the University of Virginia. Their research interests include: repair studies; waste and discard studies; Black, feminist, and indigenous approaches to science and engineering; technology law and policy; the sociology of law and technology; critical infrastructure studies; and critical communication and media studies.

Kent Wayland

Kent Wayland is an Assistant Professor in the Department of Engineering and Society at the University of Virginia. Their research interests include: technological cultural heritage and maintenance, surveillance, transparency, and data ethics, and the ethics and practice of student community-engagement projects.

Bryn Seabrook

Bryn Seabrook is an Assistant Professor in the Department of Engineering and Society at the University of Virginia. Her research interests include bioethics, public participation in environmental policymaking, energy efficiency, climate change, negotiating the environmental-consumer nexus, analyzing American consumer culture, engineering education, engineering responsibility, and disability studies.