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Building Sociotechnical Competencies through an Integration of Engineering Ethics and Science, Technology and Society Studies: A Reflection on Instructional Practices

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Introduction

With the goal of providing engineering students with a solid grounding in sociotechnical thinking, and an opportunity to explore the complexities of sociotechnical systems, engineering curriculum can draw from a combination of engineering ethics and STS (Science, Technology and Society) studies to offer students a variety of tools for assessing the relationships between technological, social and environmental development. This paper explores a set of teaching practices that combine actor network theory, the concept of affordances, reflexive principlism and care ethics within a foundational course in engineering & society to support the development of sociotechnical thinking.

More specifically, this work refers to teaching practices within a large course in engineering & society studies, offered in the second year to students as a core course in three different engineering programs, and our attempt as instructors to build sociotechnical competencies through an integration of theories and concepts drawing from different disciplinary traditions. The goal of this course is to provide students with dedicated study in the analysis of sociotechnical systems, and a toolbox of approaches and methods for ongoing engagement in sociotechnical thinking and integration in their broader engineering curriculum. The course also offers students opportunities to develop skills in written and oral communication, the facilitation of discussion, and engaging in difficult dialogues. Through lectures, weekly readings, innovative discussion-based seminars and assignments, students are provided with a scaffolded learning approach to gradually build competency in sociotechnical thinking.

By introducing the concept of affordances, students are encouraged to consider the relations that exist between humans and technological artifacts as a starting point for sociotechnical thinking. This is layered within systems thinking and Actor Network Theory (Latour, 2005), as the students build a broader understanding of sociotechnical systems as a series of relationships, representing an assembling of social, artifact, environmental and institutional actors. Through this process, we aim to acknowledge and deconstruct the idea of a sociotechnical dualism. After students begin to see technology as a system, and become more aware of its challenges and tensions, we introduce concepts and tools for identifying, describing and eventually mitigating ethical concerns. Broadly, students are introduced to the concept of ethical and moral reasoning, micro and macro ethics, key frameworks in ethics from both the absolute and relative traditions, and the ethical frameworks that garner the greatest focus in the course: reflexive principlism (Beever & Brightman, 2016) and care ethics (Tronto, 1998). Finally, students are introduced to the Design for Social Justice framework (Leydens et al, 2014), giving them an opportunity to consider how the process and outcomes of engineering design can be used to examine and address underlying structural conditions.

While we have found a logic to this layering of approaches to sociotechnical thinking, we also note challenges that students face when using these approaches. For example, systems thinking, and in particular Actor Network Theory, and its view of technologies as ever-shifting, can be challenging for students to wrestle with. As care is often viewed as something we “simply do”, convincing students of its utility as an ethics framework and as an entry point to design for social justice is something that has required creative approaches, starting with personal ethics and moving to the macro. The cognitive and affective requirements of understanding technology as a system and identifying ethical and equity-based concerns at various levels requires significant commitment from the students, despite some conceptual overlap in the relational nature of both lines of thinking.

This paper explores the major components of this curricular approach, examining four key components: Introduction of STS theory and Actor Network theory; Introduction to Ethics and Reflexive Principlism; Care Ethics; and Design for Social Justice. This trajectory of initial exploration is currently positioned in the first four weeks of the course, designed to provide students with a set of tools and approaches to consider and analyze various sociotechnical issues related to sustainability, equity and security throughout the term.

Background

The course design, drawing from different disciplinary and knowledge traditions with the aim of building sociotechnical competency, is reflective of the multifaceted lines of inquiry that comprise sociotechnical thinking in engineering. In this section, these lines of inquiry will be traced as a way of demonstrating the relevance of sociotechnical thinking and our teaching approach.

As noted by various scholars (Pawley, 2019; Riley, 2008), engineering as a profession is often embedded in a capitalist framework focused on profit and production, which may disincentivize critical thought about the role of technology and its impacts on society and the environment. These tensions are demonstrated by the micro/macro ethics divide in engineering, while professional/personal or “micro-ethics” is more prominently explored, often through the code of ethics (Hess & Fore, 2018) which focuses on engineer to client or engineer to company, neglecting broader systemic issues (Bucciarelli, 2008) or deeper questions of personal morality (Barry & Herkert, 2014). The abdication of responsibility to the market, as articulated by Pawley (2019), seems to encourage an avoidance of examining broader, macro-level issues like climate change and diversity, the broader ethical considerations of the profession and social impacts of engineering, under the umbrella of the engineering ethics curriculum. That a macro-ethics approach is insufficient has been further documented by Bielefeldt et al (2018).

Riley (2008), in a case for the inclusion of macro-ethics, specifically suggests that macro-ethics must draw from STS as a discipline of study. Further, STS scholars Johnson and Wetmore (2009) argue that if we focus on the interactions between technology and society, we gain useful perspectives on the responsibilities of engineers. Seabrook et al (2020) note that STS provides useful conceptual frameworks that enable students to see engineering problems and solutions in sociotechnical terms. They advocate for an embedded model, reflecting “engineering studies” with STS scholars and teachers integrated within engineering faculties.

Recent expression of interest in building social and ecological responsibility in engineering (Borsen et al, 2021) and a broader perspective on sustainability and systems thinking (Paul et al, 2021; Lonngren et al, 2020) demonstrate a growing interest in macro-ethical considerations in engineering. Macro-ethics may be emphasized through the emphasis of the UN declaration of human rights as a central idea to frame engineering ethics issues like privacy, security and standard of living (Bielefeldt, 2019). There is a longer history of curricular initiatives that have been developed to fully integrate liberal arts (Lucena, 2003), an important contributor to broader incorporation of macro-ethical interests in engineering.

Macro-ethical considerations, in our experience, require a fulsome exploration of relative ethics approaches which enable deeper contextual reflection. Reflexive Principlism (Beever & Brightman, 2016) offers a principle-based approach, focusing on the utilization of four principles (justice, autonomy, non-maleficence and beneficence), drawing from medical ethics. The approach encourages a reflexive orientation to specifying the use of the principles in specific engineering cases and applications, balancing between the principles, and then justifying an ethical response. The approach is inherently relative as learners and practitioners are encouraged to draw from deeper contextual knowledge as they apply principles but still draws from a framework of principles that align with a “universal morality” and the process-based application of rules and principles that is familiar to engineering.

Pantazidou and Nair (1999) and Hess et al (2017), amongst others, suggest that engineering should incorporate an ethics of care. Ethical decision making is often driven more primarily by justice and fairness, which removes the specific consideration of the individuals and communities or does not incorporate the value of concern for others as a driving motivation. Catalano (2016) furthers this argument by advocating for compassion and critical consciousness in engineering ethics, invoking the development of a deeper awareness of self, a deeper awareness and broader perspective of others and social issues, and seeing one’s potential to make change. Our instructional interpretation of reflexive principlism and care ethics is that they can and do complement each other, and so we encourage students to use both.

Tracing the development from microethics to the inclusion of STS to support macroethics and ESI (engineering and social impact), sociotechnical thinking emerged. Different ideas of the skills and competencies involved in sociotechnical have been presented, but in the earliest example of sociotechnical thinking in engineering education, Leydens et al (2018) note the importance of systems thinking, innovation, adaptations, improvements, sociocultural and ethical considerations, communication and collaboration. The authors note that practicing engineers address problems situated in real social contexts, which is echoed by Trevelyan (2014) who suggests that practicing engineers describe practice as much more sociotechnical in nature than students do, further motivating the integration of sociotechnical thinking.

Since the emergence of the Leydens et al paper in 2018, the role and importance of sociotechnical thinking has grown in the engineering education literature as a response to the presence of sociotechnical dualisms and a recognition of engineering as a broader sociotechnical practice (Rodrigues & Seniuk-Cicek, 2024). Sociotechnical Thinking has more recently been described as the ability to identify, address and integrate social and technical dimensions of engineering (Erickson et al, 2020; Mazzurco & Daniel, 2020; Zacharias et al, 2023). As noted above, the term was only just introduced within engineering education at the 2018 ASEE conference (Leydens et al, 2018), and was added to the EER Taxonomy in 2020 (Finelli, 2020).

Although the term is new in engineering education, as described by Rodriges & Seniuk-Cicek, it is built on various works on ethical thinking, social justice and the integration of liberal arts in engineering.

In their scoping review on sociotechnical thinking (STT), Rodriges & Seniuk-Cicek synthesize a number of works on integrating, teaching and assessing sociotechnical thinking skills in engineering programs. They found a strong emphasis on integrating social considerations within technical courses, and various studies examining the use of particular pedagogical strategies to build understanding of sociotechnical complexity and the role of social justice. More specifically, key themes identified include: 1) barriers to developing STT; 2) students' development of STT; 3) engineering identity, culture and STT; 4) characteristics of STT; 5) challenges in teaching STT; 6) opportunities for teaching STT; 7) incorporating prior knowledge; and 8) creating emotional connections. The STT literature explored offers many important insights about student and instructor experiences, pedagogical strategies and conceptual frameworks, and motivates numerous future directions for STT work. However, we have not identified literature that explores the integration of major theoretical frameworks or pedagogical foci to suggest a within-course STT curriculum. Our work, through an exploration of our teaching practice, aims to offer this.

It is important to acknowledge the challenges inherent to teaching in this space. In Polmear et al (2018), interviews on teaching practices related to ethics and social impacts found challenges in student interest and engagement and support for teaching, which were echoed by Tang et al (2018) and Lucena and Leydens (2015), who note the challenge of students in engineering tending to lean towards dualistic (right/wrong) thinking, or rejecting ethics curriculum on the perceived basis of political bias. The recent scoping review by Rodriges & Seniuk-Cicek, as noted above, also highlights these challenges as key theme emerging from the literature. We have experienced these challenges as instructors, although in recent years have also observed a growing interest from students, perhaps as our social and ecological challenges become even more critical and pressing, and as our students continue to build a deep desire to make a difference in the world.

Course Design and Pedagogical Approach

The course described in this paper is a core (required), second year course, offered to students in a large multidisciplinary engineering program, and as a distinct offering to students in Civil and Mineral Engineering, within a large research-focused institution. Although the course differs between these two offerings to include discipline-relevant applications, the core tools and approaches are consistent. In all three programs, the course supports a humanities and social science requirement directed by the Engineering Faculty, critical and ethical thinking required by the university's degree-level expectations, and various accreditation requirements including graduate attributes on the impact of technology on society and the environment, ethics and equity and professionalism. Although many of the pedagogical approaches used in the course are found in other courses, including those in engineering ethics and courses offered by science, technology and society studies for engineering students, we have not discovered other core engineering courses that combine this particular set of frameworks into one course curriculum, offering a new approach to consider.

We are intentional in communicating to the students that the course draws theory from STS and Engineering Ethics, and that each come with their own disciplinary traditions and sociopolitical drivers (for example, STS has strong origins in the social and environmental movements of the 1960s and 70s; and engineering ethics draws from both academic and professional engineering considerations). As noted, the course introduces key frameworks in the first four weeks, and then explores a series of three key challenges or crises: the sustainability crisis, acknowledging the catastrophic impacts of climate change and environmental degradation; the equity crisis; acknowledging the inequitable distribution of resources and how this can intersect with sustainability concerns (where skewed climate vulnerabilities magnify other inequities); and the security crisis, through an exploration of how inequities can threaten our social stability. Pedagogically, the course includes lectures in which topics and examples are introduced, and weekly, two-hour discussion seminars. Students prepare for the discussion seminars by completing the assigned readings and discussion questions, and engage through student-lead discussion, critical reading review and a variety of discussion-based activities. Their participation is assessed and typically comprises 15-20% of the course grade, signalling the significance of this activity to the course. Students are also assessed through an Actor Network assignment, in which they create a map of actors and relations, situating themselves in a sociotechnical system and responding to analysis points about key Actor Network concepts, such as punctualization and translation. Students complete a research assignment, in which they are required to integrate actor network theory with engineering ethics to analyze the impact of a technology. Finally, student conceptual understanding, and the ability to apply concepts to application areas is assessed through long-answer examinations.

The following sections provide an overview of the major conceptual frameworks introduced in the course, and the pedagogical approaches that accompany them.

STS, Actor Network Theory and Affordances

The course opens with discussions of progress and its meaning, dominating ideologies like neoliberalism, the role of our worldview in understanding socio-technical systems, and the challenging nature of learning about the interrelations between engineering and society, where we must confront ideas that can be uncomfortable, such as the incompatibility of economic growth and environmental preservation (and that our ideas of "progress" may not produce social good for all). In particular, a focus on worldview, which we define as comprising of the way we understand the world formed by our family, our culture, our ethnicity, our view of religion and science and technology, some mix of education and politics and, and environment, and even our time in history. Understanding our own worldview can deepen us as people, it can allow us to think critically about instinctive assumptions, and it can help us question dogmas. Examining worldview offers students some early reflection on their values and how they relate to moral foundations and provides students with a starting point for engineering ethics.

We express to the students early on that a goal in the course will be to view technology as a system (Croissant & Volti, 2024); to consider technology as the activities, ideas, and social visions performed and held by people, put into material form (Rossmann, 2020); and finally, that technology includes all of the knowledge, concepts, experimental processes, tangible and intangible artifacts and systems (Nightingale, 2014). We explore with the students that there's a tendency to view what is social and what is technical as distinct (Faulkner, 2007; Cech, 2013), and, as a response in the course, we aim to understand technology as a system with its many enabling parts, including policy and human decisions. Therefore, students are given reason to try to re-assemble the sociotechnical. Simultaneously, we introduce key theories from STS studies: technological determinism, social construction of technology and technological momentum, and their limitations (namely, that they offer a view that is one-directional: that social leads to technical, or technical leads to social, but fails to capture the nuanced, multi-directional relationships that exist within sociotechnical spaces), to pave the way for actor network analysis.

Students are introduced to Actor Network Theory through four major mechanisms, as previously discussed in (Irish and Romkey, 2021). First, students watch a two-part video that we constructed to introduce the concept, its origins in sociology as a reflection of the structure/agency divide, and its vocabulary, using a basic example that they are familiar with (the classroom). Secondly, we have students complete a reading by Deya Roy (2015) on the use of Actor Network Theory to analyze the Delhi water system. This paper offers a particularly good introductory description of Actor Network Theory, drawing from key theorists such as Law and Latour. Next, students participate in a seminar, in where they have an opportunity to use ANT through a network creation of a single course in their shared engineering curriculum. This provides an opportunity for students to build an understanding of the concept and vocabulary using a shared experience. Finally, students complete an individual assignment where they explore their own relationship with technology by placing themselves in an actor network, and describe key concepts including ordering, punctualization and power in the context of the network. By offering them an opportunity to explore a familiar context, students can once again focus on learning the methodology itself and what it reveals. Students explore their position in various socio-technical systems, including urban mobility, the use of digital technologies such as artificial intelligence and social media, or their experiences in workplaces or co-curricular activities.

Although in the literature we have not found this connection, we encourage students to use the concept of affordances, as a starting point, to understand and label the relationships within a system and the ways in which artifacts in particular exert power or signal use to human actors. More specifically, we draw from Davis and Chouinard (2016) and the mechanisms they outline to describe the "how" of human-technology relations (that artifacts request, demand, encourage, discourage, refuse and allow). Our experience is that this framework offers a starting point to articulating how power is exerted or felt by actors, and how the relationships in a network define the roles and production within the network; however, we are also mindful to not limit the students to this particular framework which was designed to focus primarily on human-artifact relations.

Actor network theory is used because of its positioning within STS studies. While using a basic approach to systems thinking could meet our goal of understanding technology as a system, as a teaching tool, Actor Network Theory affords a deeper understanding of the relationships and power structures within sociotechnical systems. For example, by exploring the concept of punctualization and visualizing it within a network, we can demonstrate to students the ways in which inequities can be hidden and that we need to be in tune to these hidden resistances. A challenge comes from the complex vocabulary and lack of connection with engineering examples, work and practice (as documented by Herkert, 2006); and we have received the question, “will we ever use this in engineering practice?” But our goal and role are also to introduce the students to different disciplinary perspectives and how other disciplines understand and explore the impact of technology. Students also express frustration, at times, with the idea that Actor Network Theory doesn’t provide us with an answer, but a platform for analysis; so we’ve been increasingly upfront about this to set student expectations appropriately.

Engineering Ethics, Reflexive Principlism and Care Ethics

Building a foundation in Actor Network Theory supports an early idea in our exploration of ethics: that engineering education traditionally focused on micro- or professional ethics, and while this is important, much of our focus in the course is on the macro-ethical questions about the nature of technology. By examining technology as a system, we are offering a space to further understand the ethical concerns within the macro-space.

In exploring engineering ethics, we offer key frameworks from both absolute and relative traditions, but relatively quicky converge on Reflexive Principlism (Beever & Brightman, 2016), which specifies a set of virtues, or principles, allowing for focused reasoning. While this approach comes from applied medical ethics, Beever & Brightman situate it within the engineering space, as it offers structured yet flexible ethical reasoning using four principles: (1) Respect for Autonomy, or upholding the rights and dignity of individuals; (2) Beneficence, or providing good to individuals and communities; (3) Justice, or ensuring appropriate distribution of risks and benefits across the actors in the ethical situation, and (4) Non-maleficence, or to avoid doing harm. These principles are first specified in the context of a particular situation; as a teaching tool, we offer students a set of questions to help prompt thinking around each principle. Specification moves the principles from the abstract to contextualized understanding of the principle in the situation under analysis. Balancing is the process of reviewing and settling tensions and conflicts between principles. Finally, justification requires students to justify an ethical decision based on the previous two stages. Our experience has been that students build a good understanding of the four principles, but struggle to identify tensions and balance between conflicts.

As described in (Irish and Romkey, 2024), we have more recently introduced care ethics in our teaching. There is a growing interest of care ethics in engineering, as documented above. We decided to incorporate care ethics as a way to expand students’ awareness of actors in the system (which is aided through an exploration of moral distance, or the challenge experienced in acting ethically when there is a temporal, geographic or bureaucratic distance between actors). Students are introduced to Tronto’s (1998) ethics of care framework, which includes five dimensions: (1) Attentiveness, or an awareness of who requires what care; (2) Responsibility, or recognizing a sense of obligation within a situation; (3) Competence, or knowing how to provide the care required; (4) Responsiveness, or paying attention to how are is received with a mindfulness towards power dynamics and voice; and (5) Plurality, or maintaining care and respect across diversity. To parallel the teaching approach with reflexive principlism, we have designed a set of “prompting questions” for consideration with each of the five components.

As we've experimented with care ethics in our teaching, we've noticed that care can be complementary to reflexive principlism, offering further insights on specification of the principles. However, because care ethics offers a stronger focus on the relationships engineers could (or do) hold with individuals and communities in the sociotechnical realm, we observe that it extends the engineering student's understanding of what ethical reasoning and action is; while reflexive principlism offers students principles and a process for evaluating the ethics of a particular technology or engineering project, care offers students with a process for the ongoing act of care, as they engage with communities and act ethically throughout the work, rather than simply end the ethical responsibility at "decision making".

Students are introduced to both reflexive principlism and care ethics through readings and lectures and then practice the application of both frameworks within their discussion seminars. We encourage students to compare and then use both approaches in their work but have increasingly gravitated towards the latter with the recognition that the two frameworks hold different purposes in the role of the ethical engineer. Students more intuitively connect their notions of professional responsibility to Reflexive Principlism, but less so to care; perhaps because care is typically viewed in the realm of the personal rather than the professional and is conceptualized as something "we just do". But care, like empathy, can be developed and practiced, and this is a message we convey through our teaching.

Design for Social Justice

Finally, students are introduced to Design for Social Justice (Leyden, Lucena & Nieusma, 2014), which, rather than an analytical or responsive role that engineering ethics sometimes embodies, takes a more active role in re-framing the possible realm of responsibility for the engineer. Design for Social Justice describes four approaches to engineering design: "design for technology" which focuses on addressing constraints like budget, time and functionality established by a client; "human-centered design for users", which emphasizes user needs and desires typically through ergonomics and aesthetics; human-centered design for communities, which considers projects in which the community is a resource base and encourages listening to user needs and capacities in a culturally situated way; and finally, design for social justice, which is motivated specifically towards the goal of equitable distribution of opportunities and resources to enhance human capabilities and reduce risks and harms.

Students are introduced to Design for Social Justice through lecture, the abovementioned reading by Leydens, Lucena and Nieusma, and through a discussion seminar in which they explore areas of their own privilege and disadvantage. Students are then encouraged to apply design for social justice to a project. We've explored examples such as a mental health chatbot, campus design, building science and global engineering examples, such as water collectors in Peru. Our experience is that students gain the most traction where either they hold prior contextual knowledge to practice the development and understanding, or there is a tightly scoped case study (which may not reflect the contextual nuance of a real-world situation).

Given that engineering prioritizes design as a key pedagogy and practice within education and practice, it creates an entry point in terms of how students understand their professional role as an engineer; however, Design for Social Justice is distinct from what they experience in their design curriculum, and a typical question is whether looking for structural inequities is really part of their typical role as an engineer. We address this in three ways: first, acknowledging that not every engineering activity will offer the same level of opportunity for Design for Social Justice, but that we can make equity considerations in many design contexts; secondly, that Design for Social Justice may uncover critical powerful actors that are important to note in engineering work, and finally, that problems can arise when we treat projects deserving of design for social justice as design for technology. Challenges remain in that they are not actually conducting design work in the course – a limitation that could be explored more broadly – but connections to other course tools offer motivation for using this framework.

Points of Integration

Through our foundational, core course in engineering and society studies, and as described above, we introduce students to Actor Network Theory, Engineering Ethics (and more specifically Reflexive Principlism and Care Ethics), and Design for Social Justice. We have found interesting connections and intersections between these frameworks.

For example, given that Actor Network Theory demands a focus on relationships and in fact, describes all entities as a function of the relationships within, there is a natural connection to the relational orientation of ethics, and in particular care ethics. By requiring students to examine the relationships that exist within a sociotechnical system (or network), we find they are better positioned to appreciate who and what is requiring of care when applying Tronto's framework.

Care ethics and Design for Social Justice both emphasize the importance of contextual listening; to identify underlying structural inequities, or to understand whether your care is received in a way that is intended or is legitimate for the receiver, we must "listen beyond the spec". We are encouraging students to layer these concepts; for example, apply care through the criteria within Design for Social Justice, and through care ethics, consider how identifying structural inequities may become part of the realm of engineering work. Moreover, it is a skill they are introduced to in their design courses, so it allows for some measure of integration to that work.

As noted earlier in the paper, rather than positioning reflexive principlism and care ethics as "competing approaches", we are encouraging students to use both as a way of extending their ethical responsibility to both decision making and an ongoing process. While reflexive principlism tends to enable students to evaluate an ethical concern or technology in a broader context, care ethics directs the process of engineering work and engagement with communities. Furthermore, care can expand the Reflexive Principlism principles of beneficence and non-maleficence. While Design for Social Justice is not an ethical framework, it can support engineering students in identifying underlying issues or root causes, extend ethical responsibility, and ultimately produce a more ethical response through the act of re-scoping both the problem and the responsibility of the engineer. Structural Inequities are ethical concerns in a macro-ethical framework.

Conclusions and Implications

In the course, we continually revisit Actor Network Theory (and Affordances), Reflexive Principlism, Care Ethics and Design for Social Justice, as we explore different issues within sustainability, technology & equity and matters of security (drawing from a broader definition of security, considering not only matters of conflict but also matters of privacy and meeting the social needs of individuals and communities). The overarching goal is to demonstrate the dynamic nature of technology as a system, to identify and confront ethical concerns, and to respond in a way that demonstrates care and concern for the structural conditions that underpin our sociotechnical systems.

Our approach comes with challenges, for teaching staff and students. First, these frameworks, combined with contextually rich applications for systems assessment and ethical analysis, create an intensive teaching and learning experience; these are weighty frameworks that require significant cognitive and affective commitment. Students are asked to consider novel perspectives, question their biases and confront disagreements with peers, alongside engaging in substantial theoretical learnings. Second, while the stand-alone course affords an opportunity for focused study, it may inadvertently reinforce the very socio-technical dualism we are trying to address through our approach to sociotechnical thinking, by separating the application of these tools from more technical realms. We hope to follow in the footsteps of sociotechnical thinking integration efforts at other institutions, by building further opportunities to utilize key frameworks in other engineering learning experiences. Future work will document and assess these practices, and further interrogate the integration of our various theoretical frameworks.

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