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Instructor Goals and Practices Related to Sociotechnical Thinking in the Teaching of Undergraduate Engineering Students

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As a global society, we face significant challenges, including environmental degradation and climate change, increasing economic inequity, rapid urbanization and population growth, the exclusion of individuals and groups from different forms of social engagement, and concerns with privacy and security. Given the omnipresent nature of technology and its influence on our lives, engineers must consider the ethical, environmental and sociological impacts of their work, and some engineering programs are considering new pedagogical methods and broader frameworks to engage students in macroethics, sociotechnical thinking and engineering for social justice. Using a particular perspective on sociotechnical thinking (STSE), the goal of this research was to explore sociotechnical thinking within engineering instructor teaching goals and practices. The study also sought to identify the challenges and enabling factors that engineering instructors experience in utilizing teaching practices related to sociotechnical thinking. STSE was selected given both its inherent flexibility, and its specific features that allow for some natural connections with engineering. Using STSE also allowed for the introduction of a framework from a different context to assess its utility and relevance to the engineering landscape.

This study employed an online survey, featuring both qualitative and quantitative methods, with engineering instructors at four universities in Canada, designed to provide an initial understanding and broad overview of STSE in the context of engineering education. Following the survey, a smaller group of instructors participated in semi-structured interviews, to provide a deeper understanding of instructor goals and practices related to STSE. The data offers a description of what STSE looks like in the context of undergraduate engineering education at four Canadian institutions, and bridges research and educational theory between both K-12 and Post-Secondary Education, and Science and Engineering Education.

This work demonstrated that engineering instructors employ a diversity of goals and practices in their teaching, but demonstrate a strong bend towards real-world applications through a variety of mechanisms. Instructors demonstrated moderate support for STSE, with a strong orientation towards problem solving and design, but shared concerns, in particular about exploring issues of social justice and fairness and the possibility of imposing bias on students. This is reflective of work in engineering education that highlights the apolitical nature of engineering and its resonance in undergraduate engineering programs. Finally, a reframing of STSE is offered to acknowledge the role of problem solving rather than issue exploration in engineering, while highlighting the need to further consider the context of engineering activities, aligned with recent work on sociotechnical thinking and social responsibility in engineering.

Introduction

Undergraduate engineering programs are expected – by their institutions and accrediting bodies - to explore the complex relationship between science and technology, encourage citizenship and action-taking on critical social issues, and consider the impact of engineering's work on society – the hallmarks of STSE (Science, Technology, Society and the Environment) education. STSE, which explores the interface between science, technology, society and the environment, is a well-established educational movement that has developed over the last 50 years in science education, primarily in elementary and secondary schools (Aikenhead, 2003; Pedretti & Nazir, 2011).

This research explores the teaching goals and practices of engineering university instructors, and more specifically, goals and practices related to the use of STSE perspectives in their own teaching of undergraduate engineering students. STSE is used as a theoretical framework for this research, as it represents a broad range of perspectives and instructional tools that connect science and technology with society and the environment. For example, STSE perspectives may be used through the exploration of an application of science, a discussion of the economic implications of technology, or an activity that explores the relationship between technological development and social justice. Instructors at four universities in Ontario, Canada were surveyed about their teaching goals and practices, and then a smaller group of instructors from three of the four institutions were interviewed to provide a deeper perspective on the survey findings and other themes of interest.

Although there is a body of research on engineering ethics and sociotechnical thinking, the latter of which has grown in the last ten years in particular, there is a gap in the research on how engineering instructors view the inclusion of ethics, sustainability, and the other hallmarks of STSE in their own teaching. Similarly, there is research, as evidenced by the work of the various research organizations dedicated to engineering education, on teaching in engineering, but limited research on how instructors navigate choices about what they teach and what instructional activities they employ. In fact, the study of university teaching itself is relatively new, with most studies in the field only emerging since the 1990s (Trigwell, 2010). This is paired with a corresponding growth in the professional knowledge of teaching (Carey, 2010), representing both a sharable body of knowledge about teaching, some of which is discipline specific, as well as craft knowledge, articulated as the teaching knowledge gained through experience in the classroom, observation and mentorship.

This research explores instructor teaching goals and practices, and more specifically their goals and practices related to the use of STSE perspectives in their own teaching of undergraduate engineering students. This study was designed to aid our understanding of how we fulfill educational goals related to STSE education in the engineering curriculum, which is influenced by various factors but largely set by engineering instructors. This research explores the prevalence of STSE perspectives in engineering education, and how engineering educators view the integration of engineering and social/environmental responsibility in their teaching. Further, this research opens a dialogue about teaching goals and practices in engineering, and the factors that inform, support and challenge engineering instruction, and creates a bridge between research and educational theory in the K-12 and post-secondary realms. The scholarship of teaching and learning in the K-12 and post-secondary spheres are often examined discretely, and considering curriculum as a continuum could be a more useful way to advance our understanding of teaching and learning.

Theoretical background

STSE education

STSE education is based on the premise that science education should include a variety of perspectives about science and technology – Historical, philosophical, cultural, sociological, environmental, political, and ethical (Pedretti, 1999; Steele, 2014; Zeidler & Keefer, 2003), which can help draw connections between science and the human experience. STSE education may explore a technological artifact; a process; a societal issue related to science/engineering/technology; social science content that sheds light on a societal issue related to science and technology; or a philosophical, Historical or social issue within the scientific or technological community (Aikenhead, 1994). The STSE approach can also include the examination of environmental threats, the economic and industrial aspects of technology, an understanding of the fallible nature of science, discussion of personal opinion, values and democratic action, and a multi-cultural dimension of science (Solomon, 1993). In short, STSE is an interdisciplinary educational model that seeks to explore and understand the many ways that modern science and technology shape culture, values and institutions, and vice versa (Mansour, 2009), and is reflective of "increasing attention toward science and social responsibility; a desire to humanize science; the surge of interest in nature of science (NOS) perspectives; calls for relevancy and public engagement; the environmental movement; and rallying calls for citizen science and activism" (Pedretti & Nazir, 2015).

STSE: The currents framework

Pedretti and Nazir (2011) reinforced the idea that there is no single, widely accepted view of STSE, and as a response to the complexity of STSE and its diverse approaches represented by 40 years of discourse, mapped the field of STSE through the identification of six "Currents". These Currents serve as a heuristic, a way of examining STSE discourse and practices amongst educators. The six Currents are not necessarily discrete; they sometimes intermingle or change, and include 1) Application/Design; 2) Historical; 3) Logical Reasoning; 4) Value Centered; 5) Sociocultural; and 6) Socio-ecojustice. The work by Pedretti and Nazir provides a strong theoretical framework that has significantly influenced this research study.

The Application/Design Current focuses on solving problems through the design of new technology or the modification of existing technology, and is a strong fit for engineering programs, given the emphasis on engineering design in the undergraduate curriculum. This Current focuses on problem-solving skills, experiments, design-build activities and other creative approaches. A criticism of the Application/Design Current is that it suggests we assume that there is always a need for a technology; where some problems are not best addressed by a technological fix. In engineering programs, students are encouraged to critique and evaluate engineering design, but there is often a built-in assumption that design – and implicitly, more technology – is the answer to every sociotechnical problem.

The Historical Current is dedicated to encouraging the exploration of the Historical and Sociocultural embeddedness of scientific ideas and the scientists' work. The Current emphasizes that science is an exciting human endeavour, and often a collaborative process, with a focus on the value of intellectual achievement and the potential for mistakes in a human pursuit. There is also the acknowledgement that science and technology can change as society changes, and that the development of technology parallels the development of society. The Historical Current may be explored through Historical case studies, role play and simulations, and the examination of scientists and their lives, within and related to their scientific work.

The third Current, Logical Reasoning, encourages students to examine socioscientific issues through the analysis of empirical evidence, the use of risk/benefit analysis and other decision-making models, and consideration of multiple perspectives and stakeholders, argument models, and critical thinking. Students should be encouraged to make decisions or recommendations through the generation of criteria, the analysis of evidence and the evaluation of options. The fourth is Value Centered, which is much like the third Current but with an emphasis on personal moral development and moral decision making. In this Current, students still examine socioscientific issues, but use philosophical frameworks, value clarification and moral decision-making to help analyze issues and make decisions and recommendations. The transaction of ideas and examination of character and ethical frameworks are important components. In engineering, the curriculum makes use of tools and methods congruent with Logical Reasoning, through impact assessment, lifecycle analysis and design evaluation, but leans less so on tools and methods congruent with the Value Centered Current, although with an increased interest in ethics and equity in engineering education, we are beginning to see a change in this regard.

The fifth Current is Sociocultural; that is, the development of an understanding of science and technology as something that exists within a broader social context. Learning activities representing this Current recognize that science and technology are linked to society at large and are inexorably connected to politics, economics and culture. Strategies such as case studies, issue examination, storytelling and the inclusion of alternative knowledge systems are utilized. This Current also recognizes that minority groups and those belonging to a non-western cultural group are often alienated; that science class doesn't always include alternative ways of knowing, such as Indigenous Traditional Knowledge in North America.

Finally, the Socio-ecojustice Current focuses on the critique of social or ecological problems through human action. Proponents of this Current focus on citizenship at both the local and global level, and use strategies like community projects, debates and action plans that actually encourage students to stand up for what is just. Educators may have concerns about exposing their ideology and political leanings in the classroom, creating some tension with respect to this Current.

STSE-Relevant Practices in Engineering education

In reflecting on the nature of STSE as described above, and considering the integration with engineering, we might start with exploring the nature of the engineering profession, and how that translates to the engineering education context. In a critique of engineering education, Pawley (2019) suggested that engineering students are taught that their role in economic production is management, not labour, and as a result, any efforts to integrate across employment levels to pressure social or environmental change won't work. Ultimately, engineering is, in many ways, embedded in a capitalist framework focused on profit and production, and the notion of social justice –which embraces a redistribution of resources to achieve fairness – doesn't always align.

Tensions around social justice and the corporatized nature of engineering are further exemplified by the micro/macro ethics divide in engineering - while engineering tends to focus on "microethics", including issues such as workplace accountability and professional conduct, there is a lack of attention to the underlying structural issues and broader themes around society and technology, like evaluating our systems of production and distribution of wealth.

Katz and Riley (2018) extend this argument to higher education more broadly, noting the increasing corporatization and marketization in the space, describing features like treating students as consumers, and academy translation of research to business ventures as "academic capitalism". They suggest that this treatment of higher education more broadly could have impacts on the engineering curriculum, for example, through less engagement with citizen education due to a focus on practical skills development. Pawley (2019) also draws attention to the problem of focusing on the professional role over moral development. More specifically, she notes that "Neoliberalism abdicates engineering's moral choices to the market, but as economists have articulated, the market is distorted in many ways" (pp. 450). Pawley suggests that this and related factors have made it very difficult for the engineering profession to ask the right kinds of questions about issues like climate change and diversity.

Our approach to STSE-related themes in engineering education are impacted by the views on what is considered engineering, and what is not. Baillie et al (2012) described boundaries that are drawn around what is considered "true" engineering work; and the challenges these boundaries present for sociotechnical integration. A sociotechnical dualism in the profession and the curriculum, described by others including Faulkner (2007) and Cech (2014), sometimes separates the social – encompassing economic, environmental, ethical and other related considerations, and the technical, which refers to the decontextualized components, that can be solved using mathematical tools, for example (Erickson et al, 2020). Technologies can be viewed as sociotechnical systems, but this isn't always the case – it is often that technology is viewed as material, and social is human and value-laden. We can draw from STS approaches – Actor Network Theory, in particular, to try to break the view of the social and technical as separate – but these approaches aren't widely used in engineering education. Conceptualizations like that proposed by Rossman et al (2020), which defines technologies as the activities people perform, the ideas people hold and social visions people put into material form, might be useful in supporting a way forward that considers technology itself more holistically. Likewise, Paul Nightingale (2014), in a piece for the University of Sussex's Science and Technology Policy Research Unit, provides different approaches to thinking about technology, including a techno-governance perspective that suggests technology is:

> All the knowledge, concepts, experimental processes, tangible and intangible artifacts and wide socio-technical systems that are required to recognize technical problems and to conceptualize, formulate, research, develop, test, apply, diffuse and maintain effective solutions to these problems as they change through time." (p 10).

Re-framing the understanding of "what is technical" can be a useful in supporting the integration of approaches in the curriculum that reflect a broader view on the sociotechnical.

In the engineering curriculum, there are several curricular approaches and themes that bare relevance to STSE, and provide appropriate context to this research; for example, a focus on sustainability, community-engaged learning, global engineering, and indigenous perspectives.

Ethics is a dominant focus in the professional development of engineers with respect to STSE-related practices (Hawes, 2001; Herkert, 2000; Hess & Fore, 2017), and notably, engineering licensing in Canada includes a professional examination with an ethics component, focusing on ethical codes and professional practice standards (PEO, 2021). However, there are many different priorities outlined for engineering ethics, from moral reasoning to the application of ethical theories and appreciating context (Hess, Strobel & Brightman, 2017).
To move towards an emphasis on macroethics, Conlon and Zandvoort (2010) suggest a STS approach, drawing from disciplinary studies in that space, and Son (2008) suggests the inclusion of the philosophy of technology to better emphasize a macroethics perspective. Other researchers (Lynch & Kline, 2000; van de Poel and Verbeek, 2006; Verbeek, 2006) have suggested the use of insights from STS to understand the impact of technology and how social norms and practices are used in the construction of technical systems. Bielefeldt et al (2018) examined macroethics (referred to as ESI, or Ethics and Societal Impact Issues by the authors) pedagogy and instructor perceptions, finding that the majority of respondents from a large survey felt that the relevant education was not sufficient. They also found that different instructors had different ideas around impactful pedagogical practices in this space. It is notable that scholars have started to suggest a broader, macroethics approach – sometimes called Ethics and Social Impact – which draws from pedagogy closer to STSE. Seabrook et al (2020) compared different approaches to embedded STS programs, noting that STS provides useful conceptual frameworks that enable students to see engineering problems and solutions in sociotechnical terms, and as engineering instructors increasingly consider the role of sociotechnical thinking, the integration of STS is being reconsidered. They note that some schools have stand-alone courses, taught by outside instructors, or might have embedded units in engineering courses. They suggest a third way – an embedded model that involves the instructors being embedded in engineering. They examine two such departments – the Centre for Engineering in Society at Concordia, and the Department of Engineering and Society at the University of Virginia. The authors discuss an 'engineering studies" approach, offering an opportunity to observe and study engineering culture and as a response to the absence of engineering and engineers in STS research.

Instructor Perceptions, Approaches and Challenges

There are numerous works that survey or otherwise study engineering instructors and their perspectives on the teaching of ethics. Katz and Knight (2017) investigated instructor views on how engineering ethics should fit within their own courses, and in the undergraduate engineering curriculum more generally (noting that instructors' perspectives have been understudied in the literature, despite their role in developing and delivering curriculum). This large study included 1389 survey responses from 31 institutions and demonstrated that civil engineering instructors emphasized ethical issues to the greatest extent, while electrical and mechanical instructors to the least (the focus in civil engineering is also noted in Bielefeldt et al, 2017). First year and capstone design courses also emphasized the importance of ethics more than those teaching technical courses. This study looked primarily at specific instructor characteristics and how these might impact perceptions of ethics. The authors found that male engineering instructors placed more emphasis on ethics in their own teaching, while female instructors had stronger beliefs around the importance of the curriculum as a whole emphasizing engineering ethics. The instructors with industry experience also seemed to more strongly prioritize ethics in their own teaching, congruent with the idea that instructors make pedagogical choices based on previous experience (Shavelson & Stern, 1981).

In another study (Polmear et al, 2018), 37 interviews were conducted to better understand teaching practices and perspectives on ESI (ethics and social impacts) education. Through these interviews, the instructors discussed a mix of challenges and affordances. Challenges discussed included a lack of student interest, student resistance, and the challenges in learning related content. Instructors also noted a lack of support from their Faculty, department or colleagues, a lack of training opportunities, and a need for relevant faculty development programs. Instructors noted that ethics experience might be limited to research ethics, unless one has been in industry, and many instructors didn't have their own ethics background or training as a student. Instructors also mentioned limitations related to accreditation and a crowded curriculum. There is a sense – whether instructors agree with this perspective or not – that technical content is prioritized. Although accreditation requires engagement in engineering ethics and social/environmental impact, there is a perception that accreditation itself is a "box ticking" approach that actually deters from other, more important work. There is also concern about accreditation as a force that can impact academic freedom.

The issue of instructor buy-in with an ethics across the curriculum approach was explored by Tang et al (2018); through interviews with instructors, they identified some key challenges, including lack of instructor training, lack of student knowledge of ethics, and tension between covering technical and ethics content. The authors recommend a bottom-up approach to curriculum development that fully engages instructors in identifying key learning outcomes and approaches. Lucena and Leydens (2015) specifically address the "distant" nature of engineering science courses – including mechanics, thermodynamics, electrical theory and transfer/rate mechanisms – suggesting they are subject to fewer collaborations and focus on social justice and ethics less than design courses.

A Place for STSE

There is a sense from researchers in engineering education (for example, Cech, 2014b) that social issues should be embedded throughout the engineering curriculum, and that engineers should view understanding the context of their work as a core professional skill. Engineering problems naturally have cultural, political, and environmental issues embedded within them, and engineering education has a role to play in preparing future engineers for this work. There is also a professional, public and institution-based expectation that engineering programs will contribute to positive social change and the development of engaged global citizens. Like STS studies in universities and related approaches in engineering, STSE also came to the forefront amidst an increasing focus on science for social responsibility.

STSE, as a model of science teaching, has been used with success at the elementary and high school levels to provide a broader understanding of the relationship between science, technology and its broader social and environmental context (albeit, in fairness, the integration in the curriculum is not without its challenges and tensions). In considering the possibilities for furthering sociotechnical thinking through STSE, we must consider the nature of the engineering profession – one embedded in a production-oriented capitalist framework. As noted, we need to expect tension with the idea of promoting social justice. Furthermore, engineering education is working against the sociotechnical dualism myth, which artificially separates the technical from the social, and will continue to pose challenges for the integration of STSE and related frameworks. We must be mindful of some of the key epistemological and ontological traditions in science education, which traditionally tends to prioritize the acquisition of knowledge, rather than the context within which it operates (Bencze et al, 2020). There is a similar phenomenon at play in engineering, which will create challenges for the inclusion of STSE. However, the major global issues we face require an expansion of what we count as knowledge, so that it encompasses the relational, holistic and interdisciplinary (Rennie, Venville & Wallace, 2012). Furthermore, we would be best served by moving away from the false dichotomy of content and contextual knowledge; as Blades notes in a discussion of STEM and Citizenship (2015), to understand socioscientific or sociotechnical issues like genetic engineering or waste reduction/disposal, one needs to understand the science, technology and mathematics – and the connection of this content to issues and the broader goals around citizenship.

In considering the breadth and nature of STSE, and related approaches in engineering, we see some coherence between contexts. For example, some of the work looking to extend real world applications and problem solving to broader sociotechnical challenges in engineering is reflective of acknowledging STSE beyond the Application/Design Current, and towards, in particular, the Sociocultural and Socio-ecojustice perspectives. Just as Science in Context approaches based primarily in the K-12 sector have increasingly encouraged a consideration of social justice and taking action, we see a push towards social justice in engineering, in particular as universities grow more invested in Equity, Diversity and Inclusion. To move towards social justice – as suggested by some scholars in engineering education – there needs to be a more critical and activist disposition presented, just like what Hodson (2010; 2021) is calling for with STSE and other Science in Context Approaches. More specifically, Hodson (2021) suggests a very direct line to sociopolitical activism; noting that students shouldn't only understand the social, environmental and cultural impacts of technology on society, but also the relationship to inequality, the importance of sharing and defending personal viewpoints, and learning through action. As we consider a social justice oriented approach within the STSE framework, it's important to acknowledge the student response to this approach, and the suggestion that these themes are best positioned on the margins rather than to take a central role in a course.

As we are directed towards a broader framework for "social responsibility", "sociotechnical thinking" and "ethics and social impact" in engineering, the possible alignment with STSE is reinforced, as the Currents Framework offers a flexible approach to creating a bridge between the social and technical. While STSE offers an integrated view of various perspectives, rather than looking simply at "ethics", "sustainability" or "social justice", for example, in isolation. The framework offers a broader set of questions, about the relationship amongst science, technology, society and the environment, to help us deconstruct a sociotechnical problem or engineering product. STSE education supports a belief that science education should include a variety of perspectives, and this is very much in line with a sociotechnical thinking approach. As we consider STSE, it's also important to consider some of the other related approaches in engineering. While engineering ethics and the shift to sociotechnical thinking tends to dominate the space, there are other models – service learning, global engineering and indigenous perspectives, for example, which are conceptually and contextually relevant to STSE.

Methods

This research utilized an online survey, designed for this study and representing a particular conceptualization of STSE – the Currents Framework (Pedretti & Nazir, 2011). The survey was distributed to instructors from four engineering schools in Ontario Canada, which provided an initial understanding and broad overview of STSE in the context of engineering education, and resulted in 180 surveys being completed. Following the survey, 12 engineering instructors were interviewed from three of the four sites, allowing for a deeper understanding of teaching goals and practices, more generally, and associated with STSE, along with the challenges faced and enabling factors related to implementing an STSE approach. While some of the quantitative survey results are integrated within the analysis, in this paper, the qualitative analysis is the primary focus.

The research is a component design, and more specifically in the complementary form (Caracelli & Greene, 1997), as a survey was used first, followed by semi-structured interviews that enhanced and expanded on the results provided by the survey (along with delivering entirely new insights). The use of a variety of data sources – fixed survey questions, open-ended survey questions and interviews - provided a sense of triangulation, giving an opportunity for different (and not necessarily consistent) results through different methods, both quantitative and qualitative. A naturalistic inquiry – a certain openness – was used, with a deductive approach through the use of the STSE Currents. It is possible to employ inductive and deductive methods at the same time; to both use a framework and allow for a certain sense of intellectual openness (Patton, 2002 p. 252) to new themes. As Patton notes (p. 252): "human reasoning is sufficiently complex and flexible that it is possible to reach predetermined questions and test hypothesis about certain aspects of a program while being quite open and naturalistic in pursuing other aspects of a program".

The survey provided a larger snapshot of engineering instructors, and therefore provides a more general overview of the goals and practices of engineering instructors, showcasing descriptive statistical data which provides a more succinct, albeit surface level summary of major themes across a larger population at the four institutions across Ontario. However, as recommended by Grbich (2007), when a broad overview of the population is required, it is important to allow for some descriptive, open-ended questions, forcing some inductive analysis to emerge, and so these have been included along with fixed choice questions. The interviews provided a more in-depth exploration, allowing for further depth and detail on the goals of engineering education, the relationship between their teaching subject matter and STSE, and the specific challenges or enabling factors in exploring these matters through their teaching; and more generally, how they describe their experience, perceptions, opinions and knowledge. It is important to note, however, that the interviews were not used to merely showcase some "emerging issues" from the survey. Certainly, the interviews clarified and expanded on some of the results gained from the survey, but the interviews were seen as a qualitative source of new ideas as well.
A method of interviewing based on Charmaz's (2006) "intensive interviewing" was used, permitting an in-depth exploration and the elicitation of each participant's interpretation of his or her experience. The interviews were designed to be conversational, to explore views, practices and experiences at an in-depth level, and to allow the participant and researcher to pause and ask

further questions where necessary. More specifically, the interview protocol used a hybrid of Patton's (2002) general interview guide and standardized open-ended approaches. A list of pre-determined and ordered questions were used to guide the interview; but the interviews were designed to encourage flexibility, where participants were encouraged to raise their own ideas, and new questions were developed during the interview relevant to the particular participant and their responses, offering flexibility in probing on particular subjects in greater depth, probing for clarification or elaboration. Each participant was interviewed once for approximately 60 minutes, although the specific time varied depending on the participant and the interview. The interview questions expanded on themes explored in the survey, and included primarily open-ended opinion/value questions, designed to understand how instructors interpret the relationship between engineering and society, and its subsequent role in their teaching. The interview also included open-ended experience/behaviour questions, to understand how the participant's goals and views manifested in their teaching. The results section showcases perspectives from the interviews, drawing direct quotes from the participants. Pseudonyms were used to protect the identity of the participants.

Results

Instructors were asked to consider the undergraduate courses they taught in the last three years, and rate each of a set of 41 practices on the basis of how often the practice is used in those courses. Instructors selected between "very often", "often", "sometimes" and "never". These responses were subsequently converted to a scale of 1-4, with 1 representing "never" and 4 representing "very often". Instructors were also asked to rate these practices on the basis of their importance in the undergraduate engineering curriculum overall. Instructors selected between "very important", "important", "somewhat important" and "not important", and once again, these were converted to a scale of 1-4, with 1 representing "not important", and 4 representing "very important". Figure 1 below represents a summary of all responses to all 41 STSE-related practices in the survey. Every score from every instructor, for each individual practice, was compiled (as paired responses; representing belief in the importance of the practice, and use of the practice in the classroom). Although it is somewhat arbitrary, the responses on all STSE practices were organized into four categories by splitting the responses between those who used the practices "more frequently" (responses "very often" (4) and "often" (3)) and those who used the practices less frequently or not at all (responses "sometimes" (2) and "never" (1)). Similarly, responses on the belief in the importance of the practices in the engineering curriculum were organized by those who felt they were important (responses "very important" (4) and "important" (3)) and those who felt they were less important, or not important at all ("somewhat important" (2) and "not important" (1)). Using this categorization, each paired response for the 41 STSE-related teaching practices was organized into one of 4 categories, noted in the quadrant in Figure 6.2.1. It is important to note that these groupings do not represent individuals, they represent individual responses to each of the 41 practices; and responses from many individual instructors are found across all four categories depending on how they responded to each of the 41 practices. Furthermore, the correlation coefficient was calculated based on comparing all responses from every participant on the basis of "use" and "importance" (5979 paired responses in total).

Figure 1: Summary of Use and Perception of Importance of the STSE-related Practices

STSE doesn't happen in my classroom, but it is important **1,956 responses (32.7%)**	STSE happens in my classroom, and it is important **1,883 responses (31.5%)**
STSE doesn't happen in my classroom, and it isn't important **1,983 responses (33.2%)**	STSE happens in my classroom, but it is not important **157 responses (2.6%)**

When we examine all of the practices, we see an almost equal representation in three of the four groups: (1) Responses that indicate the STSE-related practices don't happen in the classroom, and instructors feel they are not particularly important (33.2% of all responses); (2) Responses that indicate STSE-related practices don't happen in the classroom, but they are important (32.7% of all responses); and (3) STSE-related practices are used in the classroom, and they are important (31.5% of all responses). With respect to response category (1), this necessitates a deeper understanding of why STSE is not prioritized – as something of importance, or as a used practice. With respect to category (2), it is important to note that it is reasonable, and even expected, to find something to be important in the curriculum, but not have it in your classroom; but if this is the case for many engineering instructors, then where does STSE actually happen, and where does it belong? What are the barriers to inclusion for those who value this approach? Finally, with respect to category (3), understanding the motivations and enabling factors of these instructors is also important, in understanding how to support other instructors.

The same quadrant was constructed for each of the six currents, based on relevant STSE-related practices, and this is integrated with qualitative feedback in the next section.

STSE Currents and the Engineering Landscape

The survey, and more broadly, the study as a whole, used the Six Currents Framework, proposed by Nazir and Pedretti (2011) to examine goals and practices related to STSE in the engineering curriculum. The study design fostered an exploration of each of these six currents; and how they are currently explored in the context of engineering education.

Historical Current

In looking at the responses for use and importance for the four STSE related practices categorized as "Historical", 40.5% of responses indicated both a strong perception of importance and frequency of use. The practices linked to the Historical Current look to examine the Historical and cultural origination of concepts in math, science and engineering; the failures and successes in engineering, and the ways in which engineering knowledge and products are developed by individuals and the engineering community (which, clearly, have taken place over a long period of human history). As per the data overall, the instructors rated the importance with greater strength then the actual use in the classroom, although the activities associated with the Historical Current were used with greater frequency than those associated with any of the other five Currents.

The interviews also demonstrated support for Historical perspectives, and some useful commentary, with more specific examples and reflections on use. Engineering failures – and to a lesser extent, successes – are a common point of exploration in engineering undergraduate studies. David (Chemical Engineering, Institution B, Interview Response) described significant engineering disasters – including the Union Carbide Bhopal and Fitchburg disasters – and defended their relevance, noting "I think that's where we bring in the environment and social issues, discussing these…major catastrophes that have happened, and why they happened, and how we can prevent it." Jeremy (Mechanical Engineering, Institution A, Interview Response) described failure analysis as a "standard practice in engineering…studying those who have gone before us". However, Jeremy also noted that "it's usually those in the negative, what mistakes were made and how not to make those mistakes." Farid (Engineering Management, Institution C, Interview Response) described engineering successes as an important part of his teaching, noting "we look at…huge success stories in the recent past of some technological trends, and we have discussions around what makes this a success."

One instructor, Bruce, described his experience doing work with the military, and his exposure to their "military lessons learned process", in which individuals are invited to share mistakes with a focus on learning in a confidential and safe atmosphere. A more authentic and open process around learning from failure – with an emphasis on the idea that "there's something to be learned in every failure and there's something to be improved in every success" – could be transformational. In his own teaching, he uses examples and talks about the lessons learned process, noting "I actually gave a talk to engineers a number of years ago that I only talked about projects I did that failed and they were amazed. They said, well yeah, nobody ever tells about their failures". Reflecting on this, Bruce noted "I think this is a really important aspect of the relationship between engineering and society; that we be aware that we're working in a societal framework that we should criticize, that is very binary and engineering is not binary, right?"

Design/Application Current

Design activities that require students to demonstrate mastery of an engineering, scientific or mathematics concept was the most used practice of the 41 practices in the survey, according to instructor responses. However, when examining the other design/application-related practices in the survey, while there is very strong support for their inclusion in the curriculum, there is a gap between perception of importance and use of the practices overall, with a weaker correlation of 0.41. Overall, 33.8% of responses indicated that design is important and used in the classroom, with an additional 37.2% indicating that design is important but not used in the classroom. 28.9% of responses indicated that practices associated with design/application were not important in the engineering curriculum.

In examining the use of the design-related practices in the curriculum, there is a distinction between the practices that were used more or less frequently (and generally, weaker ratings in terms of importance in the engineering curriculum). The practices used more frequently reflect a more traditional approach, such as design to reflect knowledge of a concept; the engagement of multiple criteria; and the general environmental and social impact. Practices used less frequently include design for an individual challenge, design to address a sociotechnical need, and concepts of ethics and sustainability integrated within engineering design. These practices engage more subjectivity; a socio-political bend that instructors in engineering may not be as comfortable with. Finally, there is also a range of correlation coefficients for the design practices; there is a variation in the ways importance is perceived and then how much it happens in the classroom.

Through the interviews, instructors described design as an opportunity to explore the environmental and social context of engineering artifacts. James (Electrical Engineering, Institution A, Interview Response) described a reverse engineering exercise he uses in his classroom, in which students dissect an existing design to try and determine the design decisions behind the artifact. James suggested that this exercise ideally "goes beyond just the technical, and gets into things like human factors and its impact on society and the environment". Furthermore, James noted the importance of "a discussion of human factors and the thinking (about) technology from the user's point of view and from the people that it will affect", suggesting that this needs to be a "defining metric for a technology" and that this analysis should be "just part of the culture" of engineering.

In another example, David (Chemical Engineering, Institution B, Interview Response), who organizes a team-based design project with a real-world client for his students, described sample projects, particularly in the oil and gas sector, that would have a tremendous number of high-stakes environmental, technical and legal issues to consider. David discussed how he shares his own design experience as an engineer with his students, providing the example of a chemical engineering process that did not garner interest of industry or policy makers, in spite of benefits to the environment – because "hundreds of millions of dollars are invested in the Current processes and Current facilities" – in other words, the technological momentum (Hughes, 1969) that exists with the Current design. Ensuring students understand the context within which they are working emerged as something of significant importance. Julia furthered this, noting the importance of considering the social and environmental ramifications of engineering design, suggesting that "the decisions they make in a very specific project can have much larger ramifications". She noted:

> What seems like a small decision in a design sense, say when designing a process or deciding where to build a factory – how not properly understanding the environment in the sense of the society and the location of the process can have huge, negative ramifications, where in another place it might not even be a consideration. (Julia, Chemical Engineering, Institution C, Interview Response)

Sociocultural Current

The Sociocultural Current included a number of practices related to the social and cultural contexts of engineering; while 30.1% of responses indicated strong importance and frequent use (and an additional 29% of responses indicated strong importance without frequent use), it is worth noting that there is significant variation within the practices. In looking at all of the practices associated with the Sociocultural Current, there is a correlation coefficient of 0.51, representing a moderate correlation between use of the practices and perception of importance; but again, this varies significantly by practice; some practices are well-used and perceived as important; some are not well-used and not perceived as important, and in some, there is a divide between how much they are used and the importance they hold. In examining the more frequently used practices, we see activities associated with the established engineering community – specifically, industry practices, how research is conducted in engineering, an appreciation of engineering as a human endeavour, and the ways in which engineering knowledge is generated. We also see an acknowledgement of protection of the public and the public interest, which is widely accepted as an important tenant of engineering (Engineers Canada, 2020), and awareness of the laws, codes and standards associated with engineering work – the significance of these two items are also reflected in the mean rating on the perceived importance of the practices, which are the highest in the Current.

The interview participants provided unique insights both on how the culture of engineering might be explored in the undergraduate curriculum, and the need for better understanding the Sociocultural context within which you are working as an engineer. In fact, the reflections shared related to this Current were quite insightful, particularly around the latter, and the participants indicated strong support and interest in related perspectives and practices.
In considering the culture of the engineering profession itself, Paul (Civil Engineering, Institution C, Interview Response) suggested that while engineering failures are sometimes addressed in the curriculum, as noted in the discussion of the Historical Current above, he noted, "I don't think there's a whole lot of discussion about the culture of engineering that led to those problems". Phillip (Institution A, Materials Engineering, Interview) noted the interconnectedness of people within the engineering profession noting that "nothing that they (engineers) do is done in isolation, that they have all these colleagues and co-workers that they're going to be working with and whatever decisions they make is going to have an impact on people in society."

Charlie (Institution C, Computer Engineering, Interview Response) noted some of the interesting stories behind engineering, from a human perspective; hinting at opportunities for further exploration. When asked directly about whether engineering education should include some of the social or cultural aspects of engineering discoveries and failures, he noted, "The role of women which you don't see evidenced in the classroom here but is wildly evident in the advances of the field." However, when it comes to the practice of actually bringing this up in the classroom, he noted a lack of knowledge about cultural norms, despite an appreciation for the ways in which cultural factors can help shape a technology. Bruce also specifically noted the exclusion of the perspectives of LGBTQ people:

> I'm very personally interested in LGBTQ issues and so you know, that's another example. It doesn't tend to play out so much in geo-design in engineering and geology but it's another issue of a community that is certainly not listened to or treated with much respect. (Bruce, Institution B, Geological Engineering, Interview Response)

The interview participants had a lot to share about the Sociocultural context of engineering work, and the importance of students having an understanding and appreciation of the context within which they are working. Julia (Chemical Engineering, Institution C, Interview Response) noted the importance of "recognizing actively that everybody's world is a little bit different…that even within a large city, different community groups can have a large impact on engineering decisions". Bruce also acknowledged the importance of exploring diverse viewpoints, and in describing his goals for his students, reflected on the Sociocultural context that engineers – and particularly, geological engineers – will need to consider:

> They'll have to know how to drive an ATV, and they…will have to talk to the guys that run the chainsaws and they know that they'll be dealing with First Nations…I don't teach

> a course on any one of those things but by injecting those as examples it generally brings up awareness of both the environment of work and also environmental issues in particular. (Bruce, Institution B, Geological Engineering, Interview Response)

Some of the instructors described specific activities that they use in their classroom, or activities they believe to be ideal for exploring such themes. Geoff (Civil Engineering, Institution B, Interview Response) suggested role playing as a good teaching method, noting "I think you do need to have some sort of discussion and, you know, perhaps some role-playing or something like that – so students can understand how, you know what the different perspectives may be towards an engineering project". Geoff went on to explain the different stakeholders you might engage – engineers, the company, and different social groups, and noted the value in "trying to put yourself in the shoes of what, you know, what may be driving these people".

Jeremy (Mechanical Engineering, Institution A, Interview Response) noted the value in learning from others in the community, and more specifically, "service learning, so get students out and into society, meeting with people. I think that's a big learning opportunity for them." Jeremy also spoke to the importance of engagement in policy setting and creation, which falls under the umbrella of a socio-cultural perspective. He noted:

> As much as I hate to lose them as engineers I would like to see…more of them get into politics; and gone are the days where we can just let other people set policy and hope to change the world just through our technology, because technology is only part of the puzzle and if it doesn't have an accompanying support though policy and government push then it's not going to change anything. So to do so, to be instruments of change, they have to be changing at all levels. (Jeremy, Mechanical Engineering, Institution A, Interview Response)

This need for engagement in policy development is exemplified through many Current examples that involve the work of engineers – privacy and data security issues in computing, electrification of our transportation systems, and combating climate change. Very few undergraduate engineering programs in Canada offer specific public policy training, let alone specific training in cross-cultural awareness or the other competencies associated with this Current.

Socio-ecojustice Current

The next three Currents presented – Socio-ecojustice, Logical Reasoning and Value-centered, were close together in terms of reported classroom use, with 28.9%, 28.7% and 26.5% of responses indicating both frequency of use and a higher ranking of importance in the engineering curriculum respectively. The first of these three Currents, Socio-ecojustice, explores a critique of social or ecological problems, and encourages action as a teaching activity. A moderately strong correlation between practice and perception of importance exists (0.57). In examining the specific practices, there was stronger support for encouraging a consideration of the public and the public interest, citizenship and civic responsibility, and environmental protection; and less support for a consideration of social justice, globalization and practices around preventative engineering and sustainability. Once again, there is some variation in the correlation coefficient for each statement, representing the relationship between use and importance, but overall the correlation is moderately strong given the moderate use and perception of importance.

A few of the interview participants acknowledged the challenging situations engineering graduates may find themselves in, in which they need to carefully consider a sense of justice and equity when it comes to individuals and the environment, given the potential impact of the products and processes of engineering. For example, Phillip noted a connection between social justice and the interconnectedness present in Engineering, and how every decision impacts people. He provided a specific example:

> Let's say if you're working in a company who is going to be building a new part, and that part relies on some rare metal, rare earth or something like that, that can only be mined in some country, some relatively unstable country…there has to be some understanding of that chain of causation. (Phillip, Materials Engineering, Institution A, Interview Response)

David (Chemical Engineering, Institution B, Interview Response) described the importance of environmental impact statements and suggested that environmental needs are the most relevant to the problems the students are working on in his classes, noting "by and large most of our projects have an environmental aspect to them, and of course we encourage the students to…look very seriously at these things". Bruce (Institution B, Geological Engineering, Interview Response) described an environmental conundrum that he's reflected on in his teaching, demonstrating a sense of environmental ethos and an ethical issue that you might expect to find in a philosophy or ethics class: "Even if we had a pristine environment we don't know how to make what was there before so – (the issue is) with pretending that you can remediate an environment when in fact we don't even understand how the environment works."

The instructors had a lot to share with respect to encouraging social responsibility and an appreciation for social justice in the students. In a few cases, the instructors were very supportive of explicitly encouraging their students to consider matters related to social justice. While all instructors interviewed were generally in support of social justice as a concept, most had some hesitation about the encouragement of a social justice orientation in their students.

For example, Phillip conveyed a belief that engineering professors are not encouraging a social justice orientation but should be. When I pressed him on this, he shared his perspective on the role of universities more broadly in this regard:

> It has to come from somewhere. If it's not going to come from here – if you can't have this idealism at a university then where can you have it? I mean you can't. There's nowhere else for it to exist so it has to be somewhere…but it doesn't and – there's some sort of culture change that has to happen for that to come about…(it) needs to be considered as really the basic responsibility…to help shape good citizens and people that have an understanding of issues and are able to take some leadership role to start to deal with them. (Materials Engineering, Phillip, Institution A, Interview Response)

Phillip acknowledged that while he feels these themes are important, related discussions would likely take place outside the classroom, noting “I haven’t quite figured out the best way to try and introduce this in class”.

Interestingly, when Bruce was questioned about the notion of social justice and equity being considered in engineering, he demonstrated his own commitment and concerns, and finally a resistance to including it in his teaching:

> This is something that I have to be careful about and the reason is that I have very strong feelings on this, but you know…I’m not convinced that my feelings should necessarily overwhelm my teaching. I am very concerned about voice and representation and social justice issues, in particular, with the relationship between the electoral system and government representation and community, so at a personal level, right?
>
> I think it would be a tendency for me to preach about that with students and I don’t. But I feel very strongly that students should be made aware that there are communities that are disenfranchised and so on and I’d limit it, even though I feel very strongly about this – to a discussion of stakeholders and an awareness about when they’re presented with an engineering problem they need to be aware of the stakeholders and that the stakeholders that are represented in the first case by the client may not be representative.

When Bruce was asked about the approach he takes when exploring STSE-related themes and perspectives, he described introducing multiple perspectives, and encouraging students to draw their own conclusions, through an example like tar sands remediation. This was one of several examples he raised in the interview:

> Well, you know, that doesn’t turn anybody off because some of them think, well, I’m going to go to work, understanding wetlands so that we can do a better job with this. And some of them go, you know well, I’m going to try to stop them from expropriating land for the tar sands. And some of them go, well you know, this is just something to bear in mind when I work for Suncor, right? So, you’re not imposing a viewpoint.

These viewpoints from Bruce are quite illuminating, and although Bruce spoke to this in much more depth than other participants, this sentiment is reflected in other data from the study as well – that there is a need to separate personal perspectives from taught material; that engineering instructors should not share their “bias”, political perspective, or viewpoints on issues of social justice. Helping instructors to work through this hesitation – and find concrete teaching practices that are within their teaching comfort zone, and within a ‘zone of reception’ for students – will be critical to a full exploration of STSE-related perspectives and teaching practices.

Logical Reasoning Current

The Logical Reasoning Current focuses on the use of evidence, multiple stakeholders, critical thinking and other logic-driven tools for the analysis of socio-scientific or socio-technical issues. Although these methods seem to be more aligned with engineering, a smaller number of practices in the survey aligned with this particular Current. Given the practical nature of this

Current – it appears to reflect a set of tools, rather than broader approaches or ways of thinking – the design of survey items was more limited. Also, the Current indicates the application of these tools to socio-scientific issues, which are not explored as such in the engineering curriculum; the centre piece in engineering is typically the designed product or process, addressing a particular problem - which might address or contribute to a socioscientific or sociotechnical issue; but the issue itself isn't typically central to the pedagogy. Although there is moderate correlation between use in the classroom and importance, instructors rank the importance with greater strength than the use of the practices in their own classroom. In particular, engagement with sociotechnical issues – through analysis or the act of making recommendations – seems to resonate with instructors as something that is important, but most instructors are not engaging with this type of activity.

In the interviews, a question was asked specifically about the exploration of socio-scientific and socio-technical issues, which applies to this Current as well as the Value-centered Current, as in both cases the tools of the Current are applied to the analysis of such issues. Charlie (Institution C, Computer Engineering, Interview Response) noted that the issues explored in engineering tended to be more technical in nature – for example, the technical aspects of internet security, rather than the social implications: "I'd say we don't do much on how technology is used and how that might reflect back on how it should be designed." However, Charlie went on to discuss an interesting ethical issue in computer engineering – the evolution towards requiring individuals to purchase things that were once free – like content, and the ability to access files on multiple devices. He expressed concern, noting "these things are changing without any discussion except by the extremes on the internet blogs. And all being done by engineers."

Paul (Civil Engineering, Institution C, Interview Response) expressed some skepticism about the nature of issues-based education, expressing that some exposure is important, but "there's a risk of hanging your hat on something…if, you know every decade there's something new" – the implication being that as students graduate, the issue you focused on may not be in the world's spotlight for long. He spoke to the waves of environmentalism through the "greenhouse effect", "global warming", "climate change" and "sustainability", and noted "people talk a lot about sustainability but I don't know what is actually being done about it…I don't see how it's actually being employed and it really just seems like it's a buzzword. It seems empty".
However, Phillip reflected on a sentiment that there was an important place for engineers in the major issues our society faces, noting that "the major issues that we face have some sort of scientific, technological aspect to it and I think engineers are ideally suited to dealing with those problems", and then further emphasized his position:

> I think everything that we teach should be built around (issues). We…have all these core concepts and core, sort of intellectual framework that have to be passed on…But I think it should be done within a broader context. Like the reason you are learning this is because we have these very significant problems, let's say to do with the environment, resources, energy…honestly, I think everything should be built around those three. (Phillip, Institution A, Materials Engineering, Interview Response)

Value Centered Current

The final Current, Value Centered, also focuses on the analysis of socio-scientific or socio-technical issues; but using tools related to moral decision making, including philosophical and ethical frameworks and value clarification. The activities associated with this Current are used the least frequently overall, according to the survey results. Once again, a moderate correlation of 0.50 is found between the use of these practices in the classroom, and the perception of their importance in the engineering curriculum as a whole. Interestingly, the top practice in terms of classroom use was found to be the encouragement of values and/or personal or formal ethical frameworks. The overall mean score on this practice was 2.15, representing something closer to "sometimes" than "often", however, it is notable that 38% of instructors shared that they encouraged this kind of engagement, which is actually quite surprising given the general belief that ethics is marginalized in the curriculum. Fewer instructors actually provided ethical dilemmas or expected students to apply these to their work as an engineer. This is reflective of a theme in the data – the practices that involved "acknowledgement" and "consideration" were rated as more used – and more important – than the actual application of a practice or framework. As noted by Charlie (Computer Engineering, Institution C, Interview Response), "I'd like them to appreciate that the things we build have an impact on both society and environment and vice versa…and what is curious to me is at what point can they start to understand what they might do about it?" This sentiment is certainly reflected in the survey data.

It is worth noting again that ethics in engineering education – when it is taught – tends to focus on personal and professional ethics, rather than macro-level ethics that consider the breadth of a sociotechnical issue, or even the ethical considerations of a particular product or process associated with engineering. The engineering ethics case studies typically used (such as the Three Mile Island Accident, the Hyatt Regency Walkway Disaster or the Challenger Disaster, as discussed by Barry and Herkert (2015) and Colby and Sullivan (2008)) involved human error, organizational failure and violation of professional ethical standards. As noted, there are scholars advocating for the inclusion of macroethics, such as Herkert (2000) and Riley (2008); who encourage dialogue around questions about participation in engineering, making decisions on issues and problems to be addressed, and considering who is served by engineering. However, at present, the focus of ethical reasoning is primarily on the personal and professional ethics side, mirroring the focus of the Professional Engineering Examination. Therefore, the focus of Value-centeredness at the macro-level reflected within STSE may not resonate with the engineering instructors.

In the interviews, the instructors did not speak directly to the use of ethics, ethical frameworks or the consideration of values specifically, although certainly an appreciation for the values of different groups was indicated. While there was not a specific question about ethics and ethical frameworks in the interview – and perhaps this is a limitation in the study – the other questions certainly gave room for the instructors to raise this as a potential avenue for STSE-related approaches. So, while the survey results seem to indicate some use of ethics concepts and ethical frameworks in the curriculum, the depth of this is much less evident.

STSE and Engineering Beyond the Currents

Looking beyond the STSE Currents specifically, two key themes describing the relationship between STSE-related practices and engineering undergraduate education emerged: The relevance of practices rooted in the engineering conceptualization of the “real world”, and the problem-centric approach in engineering.

1. Practices Rooted in the “Real World”

The instructors discussed practices and ideas rooted in the “real world”. STSE itself is a collection of approaches designed to connect science education with the real world of technology, society and the environment – and so that “real world” essence is built into the framework. However, in engineering, there is a particular flavour of real world that emerges in the discussion of the STSE-related practices.

Case studies emerged as a common practice that could be used to explore STSE related perspectives. James shared his views on this, stating:

> Case studies are a phenomenal way, if you can find the right story to tell, for…students to see firsthand this connection between the technology they’re working on, the technical concepts they’re learning about, and its impact on society and the environment. (James, Electrical Engineering, Institution A, Interview Response)

Charlie provided two justifications for the use of case studies in exploring the relationships between engineering, society and the environment:

> One is that it’s a natural way to bring a whole bunch of different disciplinary topics together, and the other is it can be so easily individualized to the students’ interest so they can pick the case they want to work on. (Charlie, Computer Engineering, Institution C, Interview Response).

Another instructor, Phillip (Institution A, Materials Engineering, Interview Response) suggested case studies can be useful in demonstrating the “unintended consequences of engineering”. In his perspective, case studies can provide students with an understanding of “how an engineering decision to do this, build something this way or do something this way, how that has had an effect on people … for good but especially for bad.” Bruce described a geotechnical mapping course in which he has students examine data from long-term monitoring of a site with significant environmental damage and described the value of choosing an example that holds a certain amount of complexity. He noted:

> They’re basically plugging numbers in and making sure they understand how the computational approach works, but by picking that example, you know, it reinforces the fact that…these are complex environments with complex decisions. There’s a lot of policy questions and what are those policy questions?” (Bruce, Institution B, Geological Engineering, Interview Response)

Interview participants spoke about the value of having industry experience, and how this positioned one well for understanding the relevance of social and environmental responsibility, given the connection to the “real world”. For example, David (Chemical Engineering, Institution B, Interview Response) noted the challenge for academics with no industry experience, stating “these people by and large don’t see the risks at that level in the engineering profession and that’s the nature of the beast” and noted that in some European jurisdictions, universities require significant industrial experience for academic employment in engineering. Jeremy described his attempts at simulating the industry environment through course assignments:

> Sometimes…I’ll start off by saying, you’re a junior engineer in a design firm and here’s three design ideas that have been brought to your firm and your responsibility is to analyze these and make suggestions on how to reduce the environmental impact based on what you’ve learned. (Jeremy, Mechanical Engineering, Institution A, Interview Response)

Jeremy went on to discuss other examples of how he integrates cases and perspectives from industry, for example, “If I’m trying to communicate the idea of how they should be minimizing material consumption in their designs I will bring up, you know, examples of dual-flush toilets or things that are already in the marketplace”. Similarly, Frank, in discussing the integration of related themes, described his efforts with respect to capstone courses, and how he took the opportunity to engage with mining companies to determine how to integrate STSE-related themes in the work:

> Those in mine design capstone projects…are now starting to work into this some of these community and societal issues and, in fact, – you know we were struggling with how to do this and then we just asked one of the mining companies, do you actually do this?
>
> And, in fact, one of the major multinational companies when they have a project evaluation group which they set up for each major mining project and one of the people in each of these groups is tasked with looking at community relations and community, you know, needs, wants and concerns. So, we’ve sort of – we’re trying to model it so that you know, at each step of the design process or the project go, no-go process, also have input on the economic impacts, on the community and the environmental and health and safety impacts. (Frank, Mining Engineering, Institution B, Interview Response)

The focus on the “real world” is, again, unsurprising, given other work on engineering teaching goals and practices. A key consideration in engaging in meaningful STSE-related teaching practices is understanding the different ideas of “real world”, and how to ensure the real world of engineering is inclusive of the many stakeholders (human and more-than-human) that comprise the social context. In short, a broadening of what’s considered “real world” in engineering may be necessary for meaningful engagement with STSE.

Problem-Centric Approach

In reviewing the survey results and reflecting on the interviews, it was observed that while instructors feel that socio-technical and socio-scientific issues – like climate change and internet security – are important, they do not tend to use them as a driving force for teaching and curriculum development when examining the relationships between engineering, society and the environment. In comparing engineering and science, it’s noteworthy that science tends to hold a more exploratory focus while engineering offers an applied, solutions-oriented approach, which may impact the efficacy of a focus on “issues education”. A theme that emerged throughout the research - both in examining the general teaching goals and practices, and the examination of STSE-related perspectives and practices - is the relevance of problem solving in the engineering curriculum.

Jeremy described a need to expand the understanding of problems. In talking about first year students, and the relationship between engineering, society and the environment, Jeremy noted:

> I'll give them a design project to work on and they'll say, well this isn't an engineering problem. And I'll say no, you're right, that's not an engineering problem. That's an everyday problem that I want you to give me an engineering solution to. (Jeremy, Mechanical Engineering, Institution A, Interview Response)

Jeremy went on to explain that engineering solutions don't have to be technical, and noted that the skills engineering students develop - "problem solving methodology…objectivity, professionalism" are the skills needed "to design a better, more efficient heat sink for a processor, but also…famine issues in third-world countries and housing problems in first nation reservations." When I spoke to Jeremy specifically about socio-scientific and socio-technical issues, he also raised problem-based learning as an analogous approach in engineering:

> As engineers they're going to be problem solvers when they get out there. So, from that perspective I think…presenting students with problems and now coupling that with the connections to the real world so they can use real problems, I think that's a great thing. (Jeremy, Mechanical Engineering, Institution A, Interview Response)

Michael presented similar sentiments and noted his perspective on the distinction between "issues" and "problems":

> Nobody tackles climate change per se…so I don't actually see a lot of benefit in bringing that (in)…I think we would be much more successful…when we present them with problems that are much smaller. You start with defining a very small problem and then perhaps you…show them the link between the very small engineering problem and climate change. No one person is going to make a difference to climate change, other than perhaps, if a politician imposes a carbon tax.
>
> The problem is almost, you know, it's almost an attitudinal problem. You have to change the whole world's attitude towards energy, right, and I don't think it's fair to present that to students…The real question would be to present them in courses with real-word problems that are tractable, problems that they can actually perhaps imagine contributing to. And then in the context of working on those problems make them aware that that's a small piece of a large socio-technical problem, right? But if I was doing this…I wouldn't want to work from the top down. (Michael, Mechanical Engineering, Institution A, Interview Response)

The framing of STSE-related goals and practices in a more problem-centric approach is reflective of more general teaching goals and practices, which also indicated strong support for problem-solving in the curriculum. While this emphasis can be problematic in that it reduces broader issues to smaller, discrete and disconnected problems, it is a long-standing pedagogy in engineering, and should be considered in the implementation of related curriculum reform.

Discussion

Overall, this research demonstrated moderate support for STSE-related goals and perspectives, with pockets of strong support for specific elements of the framework, particularly around the Historical, design/application and specific components of the socio-cultural context. Instructors generally gravitated towards practices that are rooted in the "real world", reflective of real applications and industry practices, and in a problem-centric approach that appeals to the tradition of problem solving in engineering. The data collected demonstrated a distinction between use of STSE-related practices in the curriculum, and perception of importance in the curriculum overall, despite a moderate positive correlation between importance and use, highlighting possible barriers to implementation. In the vast majority of practices, instructors rated the overall importance of the practice in the curriculum with greater power than their use in the classroom. The survey results elicited possible reasons for this; in some cases, instructors may consider these practices to be better addressed in a specific subset of courses; but the challenges cited by instructors demonstrate a myriad of reasons why they might feel hesitant to approach these issues in the classroom. For the instructors who feel that STSE is important despite their hesitation to use it in their own classroom, there is a particular set of considerations we need to make. For other instructors, who lack engagement with STSE altogether, there are a different set of barriers we must take into consideration when designing resources and interventions.

Instructors were particularly hesitant about the implementation of a social justice orientation given the perception of their role as an "authority" in the classroom. They expressed concerns about imposing bias on their students, despite an expressed belief, in many cases, in the importance of social justice and a recognition that many people feel left behind by science and engineering. This is reflective more broadly of the findings in this work around the importance of conceptual knowledge in engineering; a positivist perspective on the nature of knowledge lends well to an authority-focused, teacher-as-expert perspective, and this is Historically reflected, to some extent, in those teaching secondary science as well (Mansour, 2009; Pedretti, 2003). Instructors seemed to be concerned that if they were to talk about social justice in the classroom, students would interpret this teaching as "truth" in the same way they would more traditional science or technical knowledge – that they might be perceived as trying to offer moral authority, analogous to their subject matter authority. A few instructors even went as far as to say that they'd discuss related issues outside of class with students, as if that somehow changed their role while they remained neutral in the confines of the classroom. In considering STSE, this issue of identity (and teacher-as expert) is of critical importance – it's not just seeing yourself as a teacher, it's seeing yourself as a teacher swimming against the perceived mainstream in engineering. Reflecting once again on the research in the secondary science context, if professional identity is not in alignment with STSE, than it won't happen (Aikenhead, 2005).

STSE was selected as a theoretical framework for this study, given the lack of related frameworks available for engineering education. Engineering ethics is relatively well established (with a focus, as noted, on professional and personal ethics and the absence of a common set of learning outcomes), and schools in Canada and many other jurisdictions are required to assess students on their understanding of the impacts of technology on society and the environment according to accreditation requirements. However, there is an absence of frameworks or tools used to inform curriculum and teaching practices in these areas. In the last couple of years, there has been increased dialogue and research on the idea of sociotechnical thinking in engineering, as researchers and practitioners encourage a shift from micro to macroethics (Riley, 2008; Johnson & Wetmore, 2009; Bielefeldt et al, 2017) and become more engaged with STS studies (Neeley, Wylie and Seabrook, 2019; Herkert, 2006) but this work is still evolving. STSE offers a multi-dimensional framework to consider the various ways that science, technology, society and the environment interact, and is worthy of consideration as the concept of sociotechnical thinking, and the bridging of the social and the technical, is further developed. The Currents give us scaffolding and many components are relevant to engineering; but modifications are needed.

While some science education scholars, such as Hodson (2010; 2021) and Santos (2009) advocate for an action-oriented approach, in which students' capacity for activism is built, we can expect that this may be resisted in engineering, based on the instructors' reaction to social justice in the curriculum and some of the experiences in the literature (for example, Catalano et al, 2010; Johnson, Leydens & Moskal, 2016; Riley, 2015). Instructors certainly appear to support Hodson's proposed first stage in a four-stage process for STSE (Hodson, 2021) – appreciating the social and environmental impacts of technology, and the cultural influences on science and technology – but the subsequent steps around recognizing inequality, formulating positions and learning through action may be out of alignment with teaching views, although the instructors interviewed did express a desire to support students in building awareness, tools and knowledge so that they could formulate their own opinions and priorities around sociotechnical issues. The design for social justice framework offered by Leydens, Lucena and Nieusma (2016) may offer another way to consider social justice in the engineering context. Regardless, we need to find a balance here – between accommodating these hesitations and pushing students on the action front to use their engineering skills and knowledge to more carefully consider the sociotechnical context.

In sum, the STSE Currents provide a useful framework for reflection on the engineering curriculum and offers an opportunity to consider the possibilities for STSE-related goals and practices. This research has highlighted some unique challenges and also opportunities for engineering; and demonstrates a need for customized framing of STSE-related goals and practices for the undergraduate engineering experience. This resonates with the challenges that have been described around macroethics and sociotechnical thinking, both of which require a broader, systems-level focus and an emphasis on collective, rather than individual change. Furthermore, STSE offers a framework to support a sociotechnical view on the work of engineers, breaking away from the sociotechnical dualism that dominates the engineering space (Cech, 2014; Faulkner, 2007) and supports a broader view of "what is technical". Work from Leydens et al (2018) and Johnson et al (2019) on sociotechnical habits of mind, as it progresses, may also be very relevant in formulating an understanding of STSE in the engineering context.

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