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Engineering, Society and the Environment in the Teaching Goals and Practices of Engineering Instructors

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Introduction

Considering societal, institutional, professional and accreditation-related expectations and requirements, and the interest from students in applying their technical skills to social and environmental issues, engineering undergraduate programs are expected to encourage students to consider the impact of engineering's work on society and the environment, explore the relationships between technology and society, and encourage students and graduates to engage in citizenship and action – defining characteristics 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 40 years in science education, primarily in elementary and secondary schools[1, 2]. The goal of this research was to explore instructor teaching goals and practices, and more specifically their goals and practices related to the use of science, technology, society and the environment perspectives in their own teaching of undergraduate engineering students. The research utilized both quantitative and qualitative methodology, employing an anonymous online survey which included both fixed-response and open-ended questions, with instructors at four Canadian institutions.

Although there is research on engineering ethics education[3,4,5,6], there is a gap in examining how engineering instructors view the inclusion of ethics and the other hallmarks of STSE in their own teaching. This research was designed to help fill this gap in the field, focusing on three key research questions: (1) How do undergraduate engineering instructors describe their teaching goals and practices?; (2) How do undergraduate engineering instructors describe their teaching goals and practices with respect to exploring the relationship between engineering, society and the environment (i.e. STSE)?; and (3) What are the specific challenges or enabling factors in exploring the relationship between engineering, society and the environment (i.e. STSE), in teaching undergraduate engineering students? The use of STSE as a theoretical framework was inspired by two motivating factors: first, STSE is a framework used primarily in the K-12 realm, and so there's a novelty to integrating the two, often distinct realms of K-12 STEM and post-secondary engineering education; and secondly, STSE represents a broad range of perspectives and instructional tools that connect science and technology with society and the environment, offering opportunities for rich and diverse responses and participation from the instructors in the study.

Background Literature

STSE gained prominence as a result of the social movements of the 1960's and 1970's that called for a change in science to include social issues, politics and the idea of responsible citizenship[7,8,9]. As citizens, we face problems involving science and technology, including those pertaining to the environment, human health, and privacy and security, and STSE instruction is designed to provide students with the tools to take on the responsibility for these kinds of problems[10]. A framework for STSE was achieved through the integration of two fields: the interactions of science and scientists with social issues and institutions, and the social interactions of scientists and their values[7]. The importance of STSE is acknowledged by the various curriculum documents from many jurisdictions that call for a science education that includes STSE perspectives[2].

STSE education is based on the premise that science education should include a variety of perspectives about science and technology – historical, philosophical, cultural, sociological, political and ethical[11,12], which can help draw connections between science, technology and the human experience. STSE education may explore a technological artifact; a process; a societal issue related to science, technology, engineering or mathematics (STEM); social science content that sheds light on a societal issue related to STEM; or a philosophical, historical or social issue within the scientific or technological community[13]. 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[14]. 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. STSE education requires a wider variety of teaching methods, including discussion, problem-solving, debates, decision-making and the use of media and community resources[13, 15] – any activities that are conducive to enhancing citizenship behaviour[16] – and includes the processes of inquiry, discourse, conflict, argumentation, negotiation, compromise, decision making and commitment[12].

An STSE-focused curriculum has various goals, which have been synthesized by Aikenhead[7]: to make the human and cultural aspects of science and technology accessible and relevant; to help students become better critical thinkers and problem solvers; to increase communication skills; encourage social responsibility; and generate interest and increase achievement in learning traditional science content. Various efforts have been undertaken to evaluate the outcomes of STSE, sometimes in comparison to more traditional methods of teaching science. A synthesis of research in the K-12 sector, conducted by Aikenhead[7,13], stated the following conclusions: (1) Students in STSE education classes improve their understanding of social issues and the interactions between science, technology and society; (2) Students in STSE education classes improve their attitudes towards science and learning; (3) Students make gains in applying science to everyday situations, critical thinking, creative thinking and decision making; and (4) Some students will enhance their socially responsible actions. In another synthesis of the research, 17 studies in 8 countries demonstrated an improvement in attitudes of the students exposed to STSE, a reduction in gender differences and a comparable understanding of scientific concepts[17]. Other studies demonstrate an improvement in learning domains such as process, application, creativity, attitude and worldview, along with more positive attitudes about science[18,19]. In summary, STSE has been shown to provide many benefits to the learner in the K-12 context.

Despite the positive outcomes, research has demonstrated numerous challenges in the implementation of STSE. A study by Pedretti et al[20] suggested that pre-service teachers expressed concern about STSE through five themes: concerns about losing control in the classroom, the necessity for support and belonging with a group of colleagues, lack of expertise in negotiating the curriculum, concern about whether politicization and action is part of the teacher's role, and concern about exposing bias and ideological bents. Similar factors were examined in a study by Gess-Newsome and Lederman[21] on biology teachers. Confidence to pursue STSE comes both from training, and the existing skills of the teacher[7, 19], and requires that the teacher's beliefs and values about science education be challenged in a way so that notions of citizenship and responsible action are integrated in the context of science[8]. In short, if a teacher's values, assumptions, beliefs, ideologies, professional self-identity, status and loyalties aren't in harmony with STSE, it won't happen[7]. It's also worth noting that science teachers – like faculty members – are normally socialized into specific scientific disciplines in university programs, where teachers are certified to be gatekeepers and spokespeople for science[7]. In return, these teachers often experience a higher status than some of their counterparts. Affiliation to subject matter is critical to a science teacher's formation of their professional identity[20], and this needs to be taken into consideration when training teachers or faculty members for STSE.

Although engineering is absent from the discussion of STSE in the literature, the themes are highly relevant to engineering education, particularly given calls for engineering curricula that are relevant to the lives and careers of students and connected to the needs and issues of the broader community, and education that includes the use of experiential activities; interdisciplinary perspectives; focus on problem-solving, communication, team and leadership skills; life-long learning; emphasis on the social, economic and environmental impacts of engineering; systems thinking; and design and ethics[22]. A review of the literature finds a good body of work on related subject matter in engineering, such as ethics, sustainability and "global engineering", but nothing that covers the breadth of STSE.

In a study on teaching practices, it's critical to examine the literature on teacher identity in the higher education context. While "teacher identity" is a well-established area of research in the K-12 literature, research is more limited in higher education. One model of university instructor identity "as teachers" was proposed by Robertson[23]. This particular model focuses on three stages of teacher identity and development: Egocentrism, where the focus is on the teacher's content mastery, using received models of teaching; Aliocentrism, where the reason for teaching is student learning and the meaning created by the learner (the professor-as-teacher sees themselves as a facilitator of learning, rather than a disseminator of knowledge); and Systemocentrism, where focus is on the learner, and how the teacher's own inner life as a learner interacts with the inner life of the student as learner. A similar model of teacher identity was described by Trigwell and Prosser[24], in which intentions ranged from the teacher transmitting the content, to the teacher employing techniques to help students change their conceptions of the content – in other words, from a focus on the teacher to a focus on the learner. Similarly, a study by Martin et al[25] found that teaching intentions ranged from the transfer of information, to a focus on the student changing their conception of the subject matter; and interestingly, the authors argued that instructors who conceive of the object of study in terms of "knowledge as given" tend to adopt more teacher-focused strategies, and instructors who view "knowledge as being constructed" adopt more student-focused approaches. This spectrum from teacher focused/imparting information to student focused/knowledge construction is also indicated in various other studies on teacher identity[26,27,28,29,30].

In summary, these models demonstrate a spectrum of teaching approaches, which typically vary from "content transmission/teacher focused" to "knowledge construction/student focused". The authors of these models indicate that there sometimes isn't a significant incentive within the university system to move beyond a focus on "content transmission", which poses a challenge for the integration of STSE, in which an instructor must allow for some diversity in student learning outcomes and look beyond what may be thought of as traditional STEM content. However, there is some indication that as instructors gain experience teaching, they may shift to a more student-centered focus. Given the nature of STSE, these perspectives could have significant impact on instructor goals and practices in the teaching of engineering.

There is a professional, public and institution-based expectation that engineering programs will contribute to positive social change and the development of engaged global citizens. STSE, as a model within science teaching, has been used with success at the elementary and high school levels. Some research has been conducted on engineering ethics, sustainability and liberal education – often as distinct approaches - in the curriculum. However, the diversity of ways something as broad as STSE may be used in engineering education, and the views of university instructors about STSE education, is unclear, which is the gap addressed by this project.

Methodology and Methods

In a recent and significant meta-analysis, Pedretti and Nazir[2] 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. The currents are summarized briefly in table 1.

Table 1: STSE Currents

Application/design	Solving problems through design of new technology or modification of existing technology
Historical	Exploration of the historical and sociocultural embeddedness of scientific ideas and work
Logical reasoning	Analyzing socioscientific issues with empirical evidence, critical thinking and decision making
Value centered	Analyzing socioscientific issues using philosophical frameworks and moral reasoning
Sociocultural	Recognizing science as existing within a broader social and cultural context
Socio-ecojustice	Critique of social or ecological problems through human action

Given the significance of this analysis, the currents framework was used as a way to investigate the relevance of STSE in undergraduate engineering education. The flexibility and breadth of this framework has encouraged the exploration of multiple perspectives in the context of this study. It is also important to note that the study was designed with a consideration for the vocabulary, context and pedagogical differences between K-12 and higher education, which meant, at times, a modification of the language around STSE, although an effort was made to preserve meaning and intention.

The methodology used in this project – an online survey - was selected and designed to explore the goals and practices of a large group of diverse engineering instructors. Although the 6 currents supported a deductive approach, a naturalistic quality was emphasized through descriptive, open-ended questions. The online survey included: 1) demographic questions; 2) questions seeking information about general teaching & learning goals and activities; and 3) questions designed quasi-deductively to explore instructors' views and practices with respect to a number of STSE-related activities and approaches, using the 6 STSE "Currents" proposed by Pedretti and Nazir. The survey underwent multiple revisions before the final version was published, and a face validation was conducted with 5 engineering instructors, to ensure the survey made sense to the population under study. The survey addressed the research questions as follows:

Research Question 1: The first research question, "How do undergraduate engineering instructors describe their teaching goals and practices?" was explored first through the question, "Describe your most important teaching and learning goals with respect to the undergraduate courses you teach. What do you hope your students will achieve by the end of your undergraduate engineering course(s)? For example, you might say 'I want my students to be highly competent in problem analysis' or 'I want my students to develop proficiency in fluid mechanics'. This question was presented immediately after the demographic information as a way to encourage instructors to think about their teaching, and set the tone for the rest of the survey before introducing themes related to STSE, and the examples provided were designed to give engineering instructors a gentle nudge towards considering both traditional content and the skills/practices we also hope to impart on students in our teaching.

A second question provided a long list of teaching, learning and assessment activities, and asked the instructors to rate how often each of them are used in the undergraduate courses they teach: Very Often; Often; Sometimes; Never. In all of the questions in the survey employing a Likert scale, a 4-point "forced choice" scale was used to encourage instructors to declare their position on either side of an "average" or "neutral" position. A caveat was added to the question, to prevent confusion: "It is acknowledged that some of these methods are more conducive to particular types and/or sizes of courses. The list of methods was constructed based on the review of the literature, and more specifically an examination of surveys used in higher education to uncover teaching and learning methods used, such as the NSSE survey, which is used at institutions across North America and beyond. There are several items listed that are known to support STSE, such as the use of real-world examples and service learning projects, but the question was also designed to include a full range of activities, from the traditional, supporting a more didactic, teacher-focused approach (such as the lecture) to the contemporary, supporting a learner-focused approach (such as peer teaching). In addition to asking engineering instructors about how often they use these activities, they were also asked to name their top 3 teaching, learning and assessment activities, with a description justifying the power associated with one of them. Overall, this question provided a sense of the instructional activities used by the engineering instructors participating in the study.

Research Question #2: The second research question, "How do undergraduate engineering instructors describe their teaching goals and practices with respect to exploring the relationship between engineering, society and the environment (i.e. STSE)?" was explored first through the question: "Examining the relationships between engineering, society and the environment should be the responsibility of: i) Instructors of a course in technology & society studies; ii) Instructors of a course in engineering ethics; iii) Instructors of engineering design courses; iv) Instructors of courses in which content is primarily mathematics, science or engineering science, v) All instructors across the undergraduate curriculum. For each of the five options, instructors were presented with a Likert scale, with four options: "Strongly Agree", "Agree", "Disagree" and

"Strongly Disagree". Instructors also had the opportunity to describe another option in an open-ended "other" textbox. This question was presented first as a way to introduce STSE, and encourage the instructors responding to the survey to consider where this should (or might) occur in the curriculum.

A considerable effort was employed in developing a set of STSE-related practices for one of the survey questions, which asked the participants to rate 41 learning activities on how often they happen in their own undergraduate teaching (Very Often/Often/Sometimes/Never) and how important they perceive them to be in the undergraduate engineering curriculum as a whole (Very Important/Important/Somewhat Important/Not Important). The 41 learning activities, which in particular went through many iterations as part of the overall survey design process, reflect the 6 STSE Currents[2] and the literature on Engineering and STSE-related practices as a foundation. It should be noted that several items represent more than one current, to represent the intermingling that occurs between the currents in practice, which is described in the original presentation of the currents by Pedretti and Nazir. For example, if one considers the sociocultural current, and the importance of understanding the social context of science, a strong link can be found to the historical current, in that the historical events and figures relevant to science and engineering are a part of the social context. One might identify with the social-ecojustice current, and demonstrate civic responsibility through the design of appropriate technology. Logical reasoning and value centered approaches may be equally valued and integrated by educators and students. Finally, no attempt was made to create an equal number of items relevant to each current; the main priority was to create a list of activities that were both relevant to STSE as a whole, and to the teaching of engineering.

Table 2: Survey Question 9 Items and the STSE Currents

Survey Question 9 Item (STSE-related Activities)	**STSE Current**
I assign a design activity that requires students to demonstrate mastery of an engineering, scientific or mathematics concept	Application/Design
I assign a design activity that requires students to consider multiple criteria (such as cost, efficiency, aesthetics, etc.)	Application/Design
I assign a design activity that requires students to consider sustainability as a design criteria	Application/Design
I require students to design a product or process to address a sociotechnical challenge (examples of sociotechnical challenges include urban sustainability and internet security)	Application/Design
I require students to design a product or process to address an individual's challenge (such as a physical disability)	Application/Design
I encourage students to consider the potential environmental impact of technology	Application/Design
I encourage students to consider the potential social impact of technology	Application/Design
I encourage my students to appreciate how society (including aspects such as politics, the economy and the interests of individuals and groups) impacts engineering activities	Sociocultural
I require my students to analyze a sociotechnical issue (such as climate change or energy management)	Logical Reasoning Value Centered
I require my students to make specific recommendations relevant to a sociotechnical issue	Logical Reasoning Value Centered
I encourage my students to use tools such as risk/benefit analysis and decision-making models	Logical Reasoning
I expose my students to the roles of stakeholders in engineering projects	Logical Reasoning
I encourage my students to consider the possibility of unintended consequences of engineering products and processes	Application/Design

I give examples of the historical and cultural origination and progression of engineering, scientific or mathematical concepts	Historical
I encourage my students to appreciate engineering as a human endeavour, which develops under the influence of individual engineers	Historical Sociocultural
I share with my students a recognition that some individuals and groups in society are under-represented in engineering	Sociocultural
I describe how engineering knowledge is generated and used by the engineering community	Historical Sociocultural
I describe how research is conducted in engineering	Sociocultural
I describe engineering industry practices	Sociocultural
I encourage my students to examine diverse knowledge systems, such as indigenous or non-western perspectives, in science, engineering and/or technology	Sociocultural
I raise the importance of cross-cultural awareness in engineering	Sociocultural
I encourage my students to develop a sense of citizenship and civic responsibility	Socio-ecojustice
I discuss the engineer's role in the protection of the public and the public interest	Sociocultural Socio-ecojustice
I encourage my students to consider their values and/or personal or formal ethical frameworks	Value Centered
I ensure my students are aware of the laws, codes and standards associated with engineering work	Sociocultural
I refer to the Professional Engineering Code of Ethics in my teaching	Sociocultural
I raise ethical dilemmas relevant to engineering work in my teaching	Value Centered
I try to build awareness of social justice issues, such as poverty or food security, in my students	Socio-ecojustice
I encourage my students to consider how engineering knowledge and skills can address social justice issues	Socio-ecojustice
I try to build awareness of environmental issues, such as pollution or resource depletion, in my students	Socio-ecojustice
I encourage my students to apply their engineering knowledge and skills to address environmental issues	Socio-ecojustice
I present the concept of sustainability and/or sustainable development in my classroom	Socio-ecojustice
I integrate a "preventative engineering" approach in my teaching, encouraging the use of practices such as life cycle analysis, pollution prevention, design for the environment and/or design for disassembly to address issues at the source, and minimize impact.	Application/Design Socio-ecojustice
I describe the relationship between engineering and public policy in my classroom	Sociocultural
I discuss globalization and its relation to engineering with my students	Sociocultural Socio-ecojustice
I encourage students to consider the engineering problems that exist within the local context	Socio-ecojustice
I encourage students to consider the engineering problems that exist within the global context	Socio-ecojustice
I expose my students to historical failures or success stories in engineering design	Historical
I expect students to apply personal or formal ethical frameworks to the design and assessment of engineering products and processes	Application/Design Value Centered
I state the possibility that the values of the individual engineer, the engineering profession, a client, and/or society-at-large may conflict	Value Centered Sociocultural
I discuss the role of engineers in engaging community members or clients in the development of engineering products and processes	Application/Design Sociocultural

The next question asked the study participants: "My approach to examining the relationships between engineering, society and the environment can be best described as: i) Incidental (whenever it comes up), ii) Existing within a purposeful course module dedicated to examining these relationships; iii) Integrated with course content where most relevant; iv) Actively integrated throughout my entire course; and v) Non-existent (do not approach it). This question was designed to provide an additional measurement of approach to STSE; however, it should be noted that all of the approaches listed (with the exception of non-existent, of course) can all be impactful and effective.

Research Question 3: The third research question, "What are the specific challenges or enabling factors in exploring the relationship between engineering, society and the environment (i.e. STSE), in teaching undergraduate engineering students?" was explored through the final two survey questions; "What are some of the challenges an engineering instructor might encounter when exploring the relationships between engineering, society and the environment in their teaching?", and "What are some of the factors that might enable or support an engineering instructor in exploring the relationships between engineering, society and the environment in their teaching?" These questions were open-ended, and designed for thematic analysis to capture the rich potential responses.

To summarize, the three research questions are: (1) How do undergraduate engineering instructors describe their teaching goals and practices?; (2) How do undergraduate engineering instructors describe their teaching goals and practices with respect to exploring the relationship between engineering, society and the environment (i.e. STSE)? and (3) What are the specific challenges or enabling factors in exploring the relationship between engineering, society and the environment (i.e. STSE), in teaching undergraduate engineering students? Key findings associated with the research questions are explored in the next section.

Analysis and Results

The quantitative questions on the survey were analyzed using descriptive statistics, while the qualitative questions on the survey, and the interviews, were analyzed using thematic analysis with a "block and file" approach[31], in which the data was organized thematically in large pieces to effectively preserve meaning from the participants. The survey received 260 unique "starts"; in other words, 260 individual engineering instructors looked at the survey. Of these 260; 197 instructors submitted some responses, in the case of 17 of these individuals, only demographic information was provided and so these responses were eliminated from the main data pool. This left 180 unique survey entries in total, which were included in the study. As instructors were given the option to skip any questions they didn't want to answer, each question elicited a slightly different population size, based on the specific questions that individuals chose to answer or not answer. The following table summarizes the basic demographic information of the survey participants:

Table 3: Participant Demographic information

Gender N=180	Female: 38 (21.1%) Male: 140 (77.8%) No Response: 2 (1.1%)
Position Type N=180	Professor (Full, Associate, Assistant or Emeritus): 103 (57.2%) Sessional or Adjunct Professor/Lecturer: 28 (15.6%) Lecturer or Instructor: 42 (23.3%) Graduate Student, Research Associate or Postdoc: 3 (1.7%) No Response: 2 (1.1%)
Academic Department	Mining, Civil and Environmental: 27

(categorized without detail to maintain anonymity of institution) N=177	Electrical and Computer 35 Chemical, Materials: 34 Mechanical, Industrial, Management and Mechatronics: 29 Mathematics and Statistics: 12 Science: 10 Social Science, Humanities and Communications: 6 Engineering Other: 18 General response provided (such as "engineering"): 6
First year teaching undergraduate engineering N=175	Median = 2000 Mean = 1998 The average is slightly lower than the median because of 5 participants w started teaching in 1975 or earlier, significantly earlier than the bulk of the data.
Years experience teaching N=175	Median = 13 Mean = 15.14 Same reason as stated above.
Industry Experience (instructors were asked to "check all that apply") N = 180	No Industry Experience = 26 (14.4%) Industry: ug or grad = 79 (43.9%) Industry: prior to aca = 78 (43.3%) Industry: sabbaticals or other short-term leaves = 31 (17.2%) Industry: collaborated teaching = 41 (22.8%) Industry: collaborated research = 93 (51.7%) Industry: consulting activities = 70 (38.9%) Industry: own firm = 24 (13.3%) Industry: partner/major contributor in firm = 19 (10.6%) Industry: Work full-time = 7 (3.9%)

Overall, the survey participants across all dimensions are quite representative of the population as a whole, with a slightly stronger skew towards newer and female faculty members in the survey population as compared to the overall population. The four institutions represent the three major institutional types in Canada: Research intensive, Comprehensive and Primarily Undergraduate, and diverse locations (large city, mid-size city and small city). The total population (based on the total number of instructors who were emailed the survey) was 1034, with the instructor population per institution varying from 28 to 463. With a survey population of 180, this produces an overall response rate of 17.1%.

Key Finding #1: Instructors in the study hold a diverse set of teaching goals and practices

The participants presented a surprisingly diverse set of teaching goals and practices, that can be organized in three categories; however, many instructors (n=116) described goals representing more than one category: i) Subject Matter Expertise (n=108), ii) Engineering Skills and Tools (n=120) and iii) Making Connections (n=91). The focus on all three of these categories is an indication of some good conditions for an STSE approach, in particular the focus on "Making Connections". Each of the three categories are explored in further depth below.

Subject Matter Expertise: some instructors simply stated that, in general, subject matter was more important; for example, "I want my students to memorize and to be able to efficiently apply knowledge and skills acquired in my course", and "Promote the internalization and retention of course concepts." Others more specifically noted their own subject matter, for example "describe key aspects of the technologies associated with energy systems" and "comprehensively proficient in the fundamentals of rock mechanics."

Engineering Skills and Tools: this category was further categorized into a number of sub-groups. It should be noted that there are certainly overlapping competencies here, but the categorization tries to emphasize key meanings as indicated by the participants.

1. Problem solving and analysis (n=58): this category, by far the largest, focused on problem interpretation, analysis and solving, for example "the most important single learning goal is to take a posed situation and formulate from it the problem to be solved", and "I want my students to be able to think clearly and analytically. Not to run screaming from a 'word problem'".
2. Critical thinking and analysis (n=30): "I desire that they critically analyze answers to develop engineering judgment, rather than plug-and-chug using a black-box approach."
3. Design (n=23): "I want my students to understand…the importance of considering human capabilities and limitations in the design of systems"
4. Quantitative tools and analysis (n=17): "critically analyze quantitative data and integrate numerous quantitative measurements to make decisions."
5. Communication (n=16): "clearly, coherently describe engineering designs"
6. Independent thinking (n=9): "the most general goal would be to give them tools to learn related material independently"
7. Creativity (n=6): "my goal was for students to think creatively"
8. Logical reasoning (n=6): "develop the ability to reason logically and recognize the potential errors in a given argument."
9. Teamwork (n=6): "describe effective design team behaviours and dynamics"
10. Research (n=6): "independently find and use further sources of relevant information"
11. Various other competencies with n=1-3: intuition, learn fast, openmindedness, lifelong learning, worldview, first principles approach, ethics, modelling, making predictions, reflection, project management, leadership, ability to build on the work of others, experimental skills and instrumentation, synthesis, learning from failure, systems thinking, business skills, organizational competency, visualization and use of tools

Making Connections: this category, like skills and tools, was organized into a subset of types, but overall, this group refers to making connections between the course material and other entity: themselves, another course, career or graduate school plans or the "real world". More specifically:

1. Application to real world engineering/real problems (n=29): "I want my students to see that physics has direct connections to real world problems."
2. Future career/graduate studies (n=18): "contribute meaningfully to the work of a structural engineering group, whether in industry or academia"
3. Integration with self/identity (n=18): "I want the students to gain confidence in their knowledge"
4. Applying knowledge in new contexts (n=13): "their ability to apply their knowledge in different contexts is what needs improvement."
5. Connection with other disciplines/courses (n=10): "Students need to learn to integrate information from many courses to arrive at practical solutions."
6. Industry connections (n=8): "I want my students to develop proficiency in basic industry knowledge."

7. Connections between technology and society (n=7): "be aware of engineers responsibilities in the human society – care about others"
8. Connect to the "big picture" (n=4): "One of my major learning goals is for students to appreciate the big picture engineering issues involved with the topic so that they may see where specific knowledge and analysis techniques fit into the bigger picture."

The reported use of a comprehensive set of teaching, learning and assessment activities are summarized in table 4, using frequency (n and % of total), mean as the measure of central tendency and standard deviation as a measure of dispersion, ordered to represent frequency of use from greatest to least. To determine the mean, each Likert scale response was converted to a number equal to 1, 2, 3 or 4, with 1 indicating "never" and 4 indicating "very often".

Table 4: Teaching practices ordered in reducing frequency by mean

Activity	Very Often	Often	Sometimes	Never	Mean (σ)
Lectures	123 (86.0%)	11 (7.7%)	6 (4.2%)	3 (2.1%)	3.78 (0.62)
Pose questions to students during lecture	89 (59.7%)	43 (28.9%)	13 (8.7%)	4 (2.7%)	3.46 (0.77)
Tutorials	96 (65.8%)	25 (17.1%)	15 (10.3%)	10 (6.8%)	3.42 (0.93)
Actively solicit questions from students during lecture	84 (56.8%)	41 (27.7%)	16 (10.8%)	7 (4.7%)	3.36 (0.86)
Use of real-world examples to contextualize course content	74 (50.0%)	47 (31.8%)	21 (14.2%)	6 (4.1%)	3.28 (0.86)
Problem sets	73 (50.0%)	31 (21.2%)	24 (16.4%)	18 (12.3%)	3.09 (1.08)
Solicitation of feedback from students about the course teaching beyond the mandated teaching evaluations	39 (26.7%)	39 (26.7%)	48 (32.9%)	20 (13.7%)	2.66 (1.02)
In-class demonstrations, to clarify an engineering, scientific or mathematics principle	41 (28.1%)	33 (22.6%)	52 (35.6%)	20 (13.7%)	2.65 (1.03)
Cooperative learning activities, in which students must work together to complete a major assignment or project using out-of-class work time	42 (29.4%)	31 (21.7%)	32 (22.4%)	38 (26.6%)	2.54 (1.17)
Major design projects	39 (27.7%)	32 (22.7%)	27 (19.1%)	43 (30.5%)	2.48 (1.19)
Design reports	39 (27.5%)	29 (20.4%)	22 (15.5%)	52 (36.6%)	2.39 (1.24)
Cooperative learning activities, in which students must work together to complete a task in-class (in lecture or tutorial, for example)	30 (20.4%)	34 (23.1%)	37 (25.2%)	46 (31.3%)	2.33 (1.12)
Labs, designed to clarify physical principles	42 (28.8%)	24 (16.4%)	16 (11.0%)	64 (43.8%)	2.30 (1.29)
Engineering modeling or simulation activities	19 (13.0%)	38 (26.0%)	53 (36.3%)	36 (24.7%)	2.27 (0.98)
Case studies	22 (15.1%)	30 (20.5%)	50 (34.2%)	44 (30.1%)	2.21 (1.04)
Student presentations to other members of the course	25 (17.2%)	27 (18.6%)	42 (29.0%)	51 (35.2%)	2.18 (1.10)
Short collaborative active learning activities in lecture, such as working in pairs on a problem	22 (15.0%)	30 (20.4%)	45 (30.6%)	50 (34.0%)	2.16 (1.06)
Discuss sociotechnical issues, such as climate change or internet security, to contextualize course content	13 (9.0%)	39 (27.1%)	50 (34.7%)	42 (29.2%)	2.16 (0.95)
In-class demonstrations for other purposes	18 (12.9%)	28 (20.0%)	50 (35.7%)	44 (31.4%)	2.14 (1.01)
Labs, designed to strengthen experimental skills	31 (21.4%)	22 (15.2%)	26 (17.9%)	66 (45.5%)	2.12 (1.21)
Laboratory reports	29 (20.1%)	25 (17.4%)	24 (16.7%)	66 (45.8%)	2.12 (1.20)
Design studios or tutorials, in which students work on design activities	25 (17.2%)	23 (15.9%)	32 (22.1%)	65 (44.8%)	2.06 (1.14)
Short individual active learning activities in lecture, such as "solve this problem independently"	13 (9.0%)	23 (15.9%)	66 (45.5%)	43 (29.7%)	2.04 (0.90)
In-class demonstrations, to encourage the development	18 (12.5%)	22 (15.3%)	42 (29.2%)	62 (43.1%)	1.97 (1.04)

experimental methods such as hypothesis building or observation					
Problem-based learning, in which a problem is introduced at the beginning of a unit or module, and is used as motivation for primarily self-directed learning	15 (10.6%)	27 (19.0%)	38 (26.8%)	62 (43.7%)	1.96 (1.03)
Discussion-based seminars	12 (8.3%)	11 (7.6%)	40 (27.6%)	82 (56.6%)	1.68 (0.93)
Essays or other writing-based assignments that are NOT design reports or laboratory reports	8 (5.5%)	17 (11.6%)	38 (26.0%)	83 (56.8%)	1.66 (0.89)
Peer assessment (students providing feedback, formal or informal, to their peers)	7 (4.8%)	16 (11.0%)	35 (24.1%)	87 (60.0%)	1.61 (0.87)
Peer teaching (students teaching each other course-relevant content)	5 (3.4%)	12 (8.2%)	36 (24.7%)	93 (63.7%)	1.51 (0.79)
Student presentations of course work to an external audience, such as through a symposium or public presentation	7 (4.9%)	12 (8.5%)	24 (16.9%)	99 (69.7%)	1.49 (0.85)
Field work, to allow students to collect data in an authentic setting	6 (4.2%)	11 (7.6%)	25 (17.4%)	102 (70.8%)	1.45 (0.81)
Field trips that are complementary to the course subject matter	3 (2.1%)	9 (6.3%)	33 (23.2%)	97 (68.3%)	1.42 (0.71)
Debates	2 (1.4%)	15 (10.5%)	22 (15.4%)	104 (72.7%)	1.41 (0.73)
Service learning projects (combines formal learning with community service)	6 (4.2%)	2 (1.4%)	10 (7.0%)	125 (87.4%)	1.22 (0.68)

Although the most and least frequently used activities are perhaps not surprising, there are a fair number of engineering instructors claiming to use some non-traditional methods as found in the middle of the table, such as cooperative learning activities (~51% using this “very often” or “often”), discussion of sociotechnical issues (~35%) and discussion-based seminars (~23%). It is also interesting to consider whether instructors tend to use a variety of activities. To determine this, the number of times each instructor signalled “very often”, “often” or “sometimes” for each practice was calculated, and it was determined that 50% of the survey respondents use at least 50% of the teaching practices on the list, demonstrating a fairly diverse reported use of teaching practices. When instructors were asked about their most powerful teaching, learning or assessment activity, again a diverse set of results presented, with top responses including lectures (n=47), interactive classroom activities (n=44), problem sets (n=35), projects (n=27), use of real-world examples (n=26), cooperative and collaborative learning (n=26), tutorials (n=24), laboratories (n=21), demonstrations (n=22), various assessment activities (n=17) and discussion/debate (n=15).

Key Finding #2: Instructors in the study believe STSE is relevant to the engineering curriculum, although there is variance in the different components of STSE and beliefs vs. practices.

When instructors were asked “who is responsible for STSE in the engineering curriculum?”, the majority agreed that instructors of a course in technology and society studies (93.9%), instructors of a course in engineering ethics (95.7%) and instructors of engineering design courses (88.7%) were responsible. However, interestingly, when asked about instructors of courses in which content is primarily mathematics, science or engineering science, 49.1% agreed that the instructors were responsible for STSE (for example, “This should be an integrated part of the entire curriculum involving all levels of contact: lectures, labs, tutorials and homework exercises”), while 50.9% disagreed (for example, “Mathematics courses seem to be too full of material to allow one to do much in this regard”). This suggests a significant divide in perspective on whether STSE related activities and concepts should be integrated across the curriculum, or exist in a sub-set of stand-alone courses in the engineering curriculum.

In the survey, participants were given a set of 41 STSE practices, and asked to rate how often they used the practice in their classroom (very often, often, sometimes and never) and how important it was in the engineering curriculum as a whole (very important, important, somewhat important, not important). These selections were converted to a numerical scale of 1 to 4 (with 4 representing "very often" and "very important"), so that the mean and standard deviation for each practice could be calculated and compared. In examining the results of the 41-item question on STSE practices, it was noted that engineering instructors rated most of the items as important in the engineering curriculum, with the currents ranked as follows from most to least important: application/design (not surprising, given the importance of design to the engineering curriculum), historical, value-centered, logical reasoning, socio-ecojustice and sociocultural. However, when examining the results around how often the instructors report this as actually happening, there is a significant difference. For example, looking at the item "I try to build awareness of social justice issues, such as poverty or food security, in my students" the mean "importance" score was 2.34 (somewhere between "important" and "somewhat important"), but the mean "use" score was 1.66 (somewhere between "sometimes" and "never"). The full results are summarized in table 5, organized by most to least utilization.

Table 5: STSE-related practices with ratings of use and importance (mean and standard deviation using likert scale data), organized from most to least utilized.

.	How often in my classroom?	How important in the engineering curriculum?
I assign a design activity that requires students to demonstrate mastery of an engineering, scientific or mathematics concept	2.83 (1.01)	3.52 (0.73)
I give examples of the historical and cultural origination and progression of engineering, scientific or mathematical concepts	2.64 (0.93)	2.76 (0.82)
I describe engineering industry practices	2.63 (0.98)	3.17 (0.75)
I describe how research is conducted in engineering	2.58 (0.89)	2.86 (0.75)
I assign a design activity that requires students to consider multiple criteria (such as cost, efficiency, aesthetics, etc.)	2.50 (1.05)	3.44 (0.70)
I encourage students to consider the potential environmental impact of technology	2.49 (1.03)	3.28 (0.79)
I discuss the engineer's role in the protection of the public and the public interest	2.49 (1.03)	3.28 (0.78)
I encourage students to consider the potential social impact of technology	2.46 (1.07)	3.14 (0.78)
I expose my students to historical failures or success stories in engineering design	2.42 (0.92)	3.03 (0.80)
I encourage my students to appreciate how society (including aspects such as politics, the economy and the interests of individuals and groups) impacts engineering activities	2.38 (1.11)	2.89 (0.82)
I encourage my students to consider the possibility of unintended consequences of engineering products and processes	2.38 (1.06)	3.12 (0.83)
I encourage my students to appreciate engineering as a human endeavour, which develops under the influence of individual engineers	2.36 (1.03)	2.73 (0.91)
I encourage my students to develop a sense of citizenship and civic responsibility	2.29 (1.02)	2.93 (0.93)
I expose my students to the roles of stakeholders in engineering projects	2.27 (1.17)	2.90 (0.87)
I try to build awareness of environmental issues, such as pollution or resource depletion, in my students	2.27 (1.03)	2.97 (0.78)
I describe how engineering knowledge is generated and used by the engineering community	2.24 (0.86)	2.69 (0.83)
I ensure my students are aware of the laws, codes and standards associated with engineering work	2.19 (1.00)	3.22 (0.74)

I encourage my students to use tools such as risk/benefit analysis and decision-making models	2.18 (1.11)	2.97 (0.81)
I encourage my students to consider their values and/or personal or formal ethical frameworks	2.15 (1.05)	2.92 (0.83)
I encourage my students to apply their engineering knowledge and skills to address environmental issues	2.14 (1.03)	2.91 (0.79)
I encourage students to consider the engineering problems that exist within the global context	2.11 (0.89)	2.68 (0.77)
I encourage students to consider the engineering problems that exist within the local context	2.03 (0.90)	2.53 (0.79)
I present the concept of sustainability and/or sustainable development in my classroom	1.97 (1.08)	2.94 (0.85)
I discuss the role of engineers in engaging community members or clients in the development of engineering products and processes	1.97 (1.05)	2.61 (0.88)
I raise ethical dilemmas relevant to engineering work in my teaching	1.95 (0.89)	2.75 (0.80)
I expect students to apply personal or formal ethical frameworks to the design and assessment of engineering products and processes	1.94 (0.99)	2.72 (0.93)
I state the possibility that the values of the individual engineer, the engineering profession, a client, and/or society-at-large may conflict	1.92 (0.96)	2.72 (0.88)
I integrate a "preventative engineering" approach in my teaching, encouraging the use of practices such as life cycle analysis, pollution prevention, design for the environment and/or design for disassembly to address issues at the source, and minimize impact	1.89 (1.04)	2.84 (0.90)
I require my students to analyze a sociotechnical issue (such as climate change or energy management)	1.88 (1.00)	2.84 (0.81)
I describe the relationship between engineering and public policy in my classroom	1.82 (0.89)	2.58 (0.81)
I assign a design activity that requires students to consider sustainability as a design criteria	1.81 (0.97)	2.99 (0.85)
I raise the importance of cross-cultural awareness in engineering	1.78 (0.88)	2.24 (0.91)
I discuss globalization and its relation to engineering with my students	1.75 (0.86)	2.46 (0.86)
I require my students to make specific recommendations relevant to a sociotechnical issue	1.74 (0.90)	2.62 (0.77)
I share with my students a recognition that some individuals and groups in society are under-represented in engineering	1.67 (0.89)	2.21 (0.93)
I require students to design a product or process to address a sociotechnical challenge (examples of sociotechnical challenges include urban sustainability and internet security)	1.66 (0.90)	2.71 (0.80)
I try to build awareness of social justice issues, such as poverty or food security, in my students	1.66 (0.87)	2.34 (0.86)
I refer to the Professional Engineering Code of Ethics in my teaching	1.64 (0.87)	2.74 (0.85)
I encourage my students to consider how engineering knowledge and skills can address social justice issues	1.56 (0.77)	2.28 (0.91)
I require students to design a product or process to address an individual's challenge (such as a physical disability)	1.51 (0.82)	2.44 (0.79)
I encourage my students to examine diverse knowledge systems, such as indigenous or non-western perspectives, in science, engineering and/or technology	1.47 (0.71)	2.02 (0.81)

In examining the data across all 41 practices (examining the response for every participant and every practice), a close to equal number of participants reported that STSE doesn't happen and is not important (33.2%), that STSE happens and is important (31.5%) and that STSE is important but doesn't happen (32.7%), although there is some variation between currents: with respect to application/design, there's a slightly higher proportion of people that say it's important but doesn't happen in their classroom (37.2%); likewise logical reasoning (37.8%) and value centered (36.8%), while sociocultural (29%), historical (24.4%) and socio-ecojustice (31.9%) fall lower, as these currents are not as highly prioritized by the engineering instructors surveyed.

Finally, when instructors were asked to select their approach to examining the relationships between engineering, society and the environment, 42.8% indicated it was incidental (whenever it comes up); 30.2% indicated it was integrated with course content where most relevant; 12.6% indicated it was actively integrated thoughout the entire course and 3.8% indicated it existed within a purposeful course module. Again, any one of these approaches can be effective, although one might interpret from this that instructors are addressing STSE primarily incidentally or when it's easiest to address. The hesitation or limitations to using STSE can be explained, in part, through the third key finding.

Key Finding #3: Challenges to using STSE are significant, and similar to those found in the K-12 teaching community.

Understanding the challenges that deter instructors from using a STSE approach in their teaching is essential if we have a goal of more broadly encouraging this model of teaching. In the survey, instructors were asked, "What are the challenges an engineering instructor might encounter when exploring the relationships between engineering, society and the environment in their teaching?", and thematic analysis was used to identify several key themes. From most to least frequent, challenges were noted as:

1. Student interest, experience and motivation (n=45)
   Content relevance (n=30)
2. Insufficient room in the curriculum (n=29)
3. Instructor training/knowledge (n=20)
4. Concerns with the themes, activities and assessment associated with STSE (n=18)
5. Insufficient instructor time, resources and motivation (n=14)
6. Concerns about imposing bias (n=8)
7. Concerns with support from peers and departments (n=6)
8. Social issues and perception of STSE (n=6)

Student interest, experience and motivation (n=45): Many instructors described the challenges sitting on the learner side of the equation. Noting a "reluctance of some students to deal with open ended and ambiguous questions" and "an attitude from students that those aspects are not important, only the technical skills are important." Some instructors indicated that students lacked the background necessary to understand the concepts, and that students "must be well informed" to engage in STSE. Instructors also expressed concern that students don't have the "critical analysis" abilities, and that "students need to convert the problem into their own framework, [and] they often don't have the background, or experience to do this." Students were accused of lacking the "emotional maturity to consider and debate", being "often more interested in employment opportunities after graduation" and too great a concern with "how to get the right answer on the test". Some instructors suggested that "larger societal and environmental issues are rarely important at their age", and that "the students are mostly quite young and inexperienced as to how the world works in practical terms".

Some instructors attributed the problem to more fundamental characteristics of the students, such as "highly heterogenous student populations, especially regarding culture and lived experiences", noting further, "it's one thing to have healthy debate; it's quite another one people feel like outliers (or, worse, outcasts) because of where they come from and where they're going." One instructor noted "it can be more difficult for students with weak English-language skills", with another suggesting that "it can be a difficult matter to get all students to participate equally, due to different levels of English language mastery and engagement with the subject", which ties into the types of assessments that STSE tends to encourage. Some instructors suggested that the student's academic or knowledge background is problematic, for example, one instructor who noted that "the students that we get in first year leave a lot to be desired (both from a high-school background perspective and family guidance.)" Finally, others expressed concern about conflicting with student's background in terms of their perspective on things, for example, "there may be some individual sensitivities to certain topics depending on students' background and level of activism".

Meanwhile, some instructors did not hold back when it came to critiquing their student population. For example one instructor noted that "some students can be indifferent and others are close minded anchorites whose opinion you cannot change". Another instructor suggested that "the fact that undergraduates often do not pay attention to what's going [on] outside of their own sphere – problem sets, immediate coursework. Many have no clue about real-world politics, events, developments and the impact that it has on what they are doing (and vice versa)." Some blamed this on their age, such as one instructor who stated that "students are also very young; many do not have the maturity or the capability to fully understand the ramifications of their future career on society and our world", which was echoed by another instructor, who shared that "lack of life experience in students means some students don't believe engineering has aspects other than math and science". A few final quotes complete a picture that essentially pins much of the responsibility for the challenges on the students:

> *"The biggest challenges I have found are: 1- Stunning levels of historical ignorance, which means that students have no clue about the roots of the various contexts in which they, and society function. 2 – Ditto for cultural ignorance. Even about their "own"/dominant culture! If one doesn't appreciate that there is a cultural framework within which one functions, how can one appreciate that other's might have different cultural perspectives???"*

> *"The biggest issue I've faced is students who have a narrow view of why they are there and what they should be learning (typically WASP mail students in my personal experience) and wonder why we need to discuss this at all. They think of engineering as something that they will do for a community but in a rather elitist sense of going and solving the problems without necessarily asking what the real needs are!"*

> *"Most engineering students tend to only be thinking of their next test or assignment or their marks. In that sense they are like feral animals. Getting them to think in terms of big picture is hard because they lack the time and the sociological knowledge to understand their place in a larger chorus. Getting them to understand the needs of their fellow man/woman is one thing…let alone getting them to appreciate non-human entities like plants and animals and the environment."*

Content Relevance (N= 30): Several instructors expressed a concern that their teaching subject matter wouldn't allow for an exploration of STSE-related subject matter or activities, given the lack of content relevance, for example, "The main challenge would be that this topic does not naturally arise in the engineering curriculum I am teaching". For some instructors, this was a practical issue, for example "The relationships between engineering, society, and the environment are broad and multidisciplinary while most courses are narrowly focused and taught by an individual specialist. It can be difficult to explore all the relevant issues in one class, and this may not be within the mandate of that one class." Some instructors reported a concern that STSE could take away from their curricular aims, for example, "Depending on the context, the ESE [engineering, society and the environment] topic might seem out-of-place or a 'distraction'", and another instructor, who stated that "most fundamental courses (focused engineering science and mathematics) don't lend themselves to digressions into discussion about engineering and society." More specifically, some instructors linked the challenge to their specific subject matter. For example, one instructor noted:

> *For courses similar or related to mine (essentially the purest mathematics an engineering student will ever use), I don't really see the material as engineering material. I see it as a tool that an engineer would use to solve real problems, and knowledge which is foundational to any scientist or engineer. It is independent of society and the environment, and the role of the relationships between these and engineering is just not directly relevant in a Mathematics course. I suppose in this context the difficulty lies in how to make these relationships relevant to topics of pure Mathematics.*

Another instructor expressed a concern about making a link to the specific teaching matter: "Incorporating a discussion of society and environment when the curriculum already has a narrow focus on design concepts", which was a surprise, given the linkages between design and STSE. Another instructor described the challenges around making connections to a particular discipline: "As an educator in Electrical and Computer Engineering there are fewer obvious connections to our impact as engineers on society and the environment, as there are in other departments, such as waste-water treatment in Chemical Engineering. However, this is no excuse as there certainly are many other ways that this can be approached that are specific to our field, it just requires more time and effort to create an appropriate experience in this area." One instructor suggested that the content doesn't belong in the classrooms of engineering instructors:

> *Spending class time to explore the relationships between engineering and society does not make sense in most engineering courses. The job of an engineering curriculum is to give students the hard technical skills. This is our first and foremost goal. Attempts to introduce societal issues in engineering courses are window-dressing at best. This is not to say that I believe that such issues are not important or shouldn't be taught. Quite the opposite is true. I believe that they are utterly important for students' future career. But teaching this within the engineering curriculum does not work!*

Insufficient Room in the Curriculum (N = 29): Linked to the issue of content is the assertion by several instructors that there simply isn't enough room in the curriculum to add more content "in the already demanding timeline". As noted by one instructor, "the question from instructors might be, "okay, I can include societal issues in my course, what do you want me to take out?" Although university instructors typically do not have a traditional curriculum document to follow as in K-12 education, and they do have academic freedom, however the links between courses in engineering are much stronger, and there's also a concern about disappointing colleagues: "The courses I teach struggle with the conflict between content and concepts ... adding more material would cause the course to explode. To remove content would cause my colleagues to explode." And "There is already too little time during the term to discuss the core mathematical curriculum. While mathematics should inform our discussion on these issues, my primary responsibility is to lay the foundations for the students' other courses". Further, another instructor notes "we are always in a time crunch to cover necessary material and if the big picture is not deliberately included in the curriculum it is harder to take a pause to talk about it." Instructors expressed concern that adding STSE "deters the coverage of the technical content to sufficient breadth and depth". There is also a sense of frustration with the crowded curriculum; based on the report from one instructor:

> *Not sufficient time to discuss such issues, as we are always struggling to add more and more material in our lectures, as a result of trying to do too much with too little! Nowadays we are training 'hybrids' because of the so-called 'new and innovative programs' that are nothing but marketing ploys. We are not educating students; we push them through the system, in order to satisfy politicians and administrators, who have nothing to do with education, or have never taught a course or done any research.*

Instructor Training/Knowledge (n=20): The instructors described concerns about a lack of training and knowledge needed to explore the relationships between engineering, society and the environment. One instructor noted, "most engineering professors are experts in their own narrow domain and many will never have thought seriously about these contemporary issues." In part, this points to a lack of training, with one instructor suggesting that "the instructor simply may not have had much training on these topics in his/her own education.", while others suggest that with instructors, there is a "lack of experience in the 'real world'. I came across many academic papers that are not grounded in reality. Professors should be encouraged to consult in industry, spend sabbaticals in industry and we should only hire those that have 5 years work experience (at least), not those that come through the post-doc pipeline". There is also considerations to be made about lack of confidence linked to this training and knowledge, with one instructor stating "though I try, I am something of an imposter.", and another instructor stating "my knowledge is experiential and I don't have the time to develop a stronger foundation myself. I worry that I might contradict something that they learn from a more knowledgeable instructor, thereby reducing my credibility."

Concerns with the themes, activities and assessment associated with STSE (n = 18): A few instructors felt that the assessment of learning when using a STSE approach had its challenges, noting that the evaluation of student learning required "developing appropriate assessment tools" and that there was a "need for most course content to be translatable questions appropriate for a final exam", demonstrating a more traditional paradigm of student assessment. One instructor suggested that "TAs often have more trouble grading this". A few instructors also noted that

STSE requires a particular set of activities, for example, “it is best taught in a discussion forum, not a traditional lecture style”, and suggesting that “Teaching large classrooms make it difficult to engage students in in-depth discussions”.

More instructors, however, described issues or challenges with respect to the themes of STSE. The challenge of linking to real-life experiences was discussed, for example, “The problem is that what the students see in society (the damages the engineering organizations and firms inflicting) cannot be encountered in the classroom”, and “the inability to properly link the teachings with experiences”. The “Diversity of social issues” was mentioned, along with “coming up with timely examples” were raised. A few instructors pointed towards a concern with respect to a lack of rigour; for example, “Providing a superficial view ‘global warming is bad’ is not useful for the students to use their quantitative skills in analyzing an issue”, and another instructor notes “the biggest challenge is that non-engineering issues are not quantitative and often do not make sense. Therefore, it is difficult to discuss them in an objective manner that is different from ‘opinion’, but is, actually, logic supported by evidence.” Furthermore, there is a deep rooted belief in engineering that action should be guided by rigourous analysis, as described by one instructor:

> *Current textbooks and materials tend to be presented from a sociological perspective focused on pointing out impacts of technology but rarely explaining to students best practices and sound systematic analytical design techniques that would help to a) identify potential negative impacts on users/society and environments; and b) creatively mitigate potential negative impacts through systematic design considerations.*

Finally, there is a sense in engineering of enabling the students to walk away from the course with something concrete that they can apply. As noted by one instructor, “How do you translate this kind of learning into a tangible skill that students have when they walk away from the course? The perspective on its own is very important, but it is difficult to create a problem solving experience that truly develops skills in dealing with engineering-society-environment issues head on.”

Insufficient Instructor Time, Resources and Motivation (n=14): Some instructors acknowledged the “additional time required to incorporate this type of content and keep it fresh”, and that “generally these are resource intensive teaching activities”, noting “growing class size” and a “lack of educational material to use to incorporate this content into the course context.” Instructors also noted that instructors might have a “resistance to doing the extra work” and that “it would require too much work for him/her to learn that relationship well enough to present it to the class or to lead a discussion about it”. One instructor suggested that there are “faculty that don’t regard this as a good way to spend time in an engineering education”, and that “some skepticism and inability/unwillingness to address messy problems holistically” exists.” One instructor suggested that the responsibility should sit with others: “Getting too embroiled on a political topic that is best left for ethics courses and the respective professional engineering organizations of the region.”

Concerns About Imposing Bias (n=8): The imposition of bias was not a particularly strong theme, but was noted by a few instructors and is an interesting consideration. For example, one instructor noted the "risk of imposing one's opinions on relative importance of the various components (i.e., engineering, society and environment) which is a complicated space with multiple stakeholders and perspectives". A few instructors questioned their role and rights as an instructor, such as one instructor who posed the question, "if a student chooses to value the short term over the long term, does an instructor have the moral right to tell the student they're wrong?", and another who noted "I'm in a position of power, and if they don't agree with my point of view, it is often perceived as intimidation." The issue of neutrality in the classroom was raised, with one instructor noting "While I believe that it is important for the students to develop an understanding of these issues, I also feel that some level of political neutrality is appropriate in a position of authority and am therefore hesitant to bring too many policy or social justice issues into the classroom." Another interesting comment from an instructor focused on an uneasiness of knowing how and when to use particular terminology: "Many decisions/topics are value laden. [Instructors] might be uncomfortable speaking to these issues. Uncertain as to how class might react, what is the appropriate language. For example, when referring to putting an engineering project in certain areas of Canada, does one refer to the indigenous population as 'indigenous', native, aboriginal, indian, metis, inuit." Finally, one instructor described a need to connect with the students in a meaningful way, describing the challenge as "conveying the real motivation and incentives for exploring these relationships in a manner that will resonate with the students and not come across as preaching."

Concerns with support from peers and departments (6): A small number of instructors noted the challenge in engaging in STSE without the support or collaboration of peers or others in their department. For example, the Electrical and Computer Engineering instructor who noted that there are fewer obvious connections with the subject matter, also noted that STSE "is less a part of the natural culture within our department and is not valued as much as it should be at the curriculum design level." One instructor noted "limitations due to team teaching and buy-in from other instructors", with another instructor noting the challenge of "trying to integrate activities across courses in the same or in different terms", noting a perceived need to collaborate with others to roll out STSE in a meaningful way (and the reality that several courses are team-taught in engineering). Another instructor described a departmental culture that made STSE challenging: "It strikes me as a little fake to go in a class and talk about social issues such as gender when these topics are suppressed, even taboo, among the faculty. In sum, the greatest support would come from the administration, not the individual faculty members."

Social Issues and Perception of STSE (n = 6): Finally, a few instructors noted concerns with respect to society's (and engineering's) interpretation and sharing of these issues that could impact their teaching and learning activities. For example, one instructor noted "the existing dogma that "our job is separate from our social and personal life"" as a barrier to STSE. Another instructor pointed at problems with the communication of science: "These issues come up in various projects, the main challenge is getting students to think beyond the rubbish about climate change, for example, that pollutes the media." Finally, one instructor noted their frustration with the analysis and presentation of social and environmental issues:

The single biggest challenge is that there is no consensus on environmental and societal issues, and motivation is highly problematic in such a messed up world. Even a cursory examination of Canadian society demonstrates some of the problems. Examples: Women earn 70% of what men earn. This is a problem. Women are 77% likely to be awarded sole custody in the event of divorce. This is not a problem. Women are underrepresented in engineering. This is a problem. Men are underrepresented in university in general (about 60% women). This is not a problem. Elementary school teachers are 90% women. This is not a problem. Engineering professors are ~90% men. This is a problem. See the issue? Maybe you don't, but half of society likely does. Pick any other major topic you want within the environment and/or society and you will see the same messed up societal situation.

Conclusions

Based on the analysis conducted, there is some enthusiasm for STSE, or practices associated with STSE, in undergraduate engineering education, as demonstrated by the support for various STSE practices and by the variety of teaching goals and practices discussed. The instructors surveyed, in particular, described a very diverse set of overall teaching goals, often indicating that content, skills and making connections were an important part of the educational experience. Of course, it is important to note that goals and practices don't always align, which is a window to an interesting follow-up to this study; an examination of what actually happens in the classroom, and what instructors might be willing to try to ensure their teaching goals are met. Regardless, a diverse and meaningful met of goals was indicated – demonstrating a certain thoughtfulness about teaching and learning.

The research also indicates that there's a significant disparity between the perceived importance of STSE-related practices and their actual use in the curriculum. This disparity varies depending on the specific practice and over-arching current, but it exists for essentially all 41 practices examined. Although not every practice can practically happen in every engineering classroom, one begins to question where it's happening or could happen, if everyone thinks it's important but people are rarely practicing it.

The hesitancy around STSE is explained through a number of challenges described by the instructors, and it is particularly interesting to note the strong suggestion that student interest, experience and motivation lacks. One of the motivating factors for this study was a set of ongoing conversations with students who want to see engineering phenomena in the context of social and environmental challenges, and want the opportunity to tackle these challenges and make a difference. A logical way forward in this research may be a comprehensive examination of how students feel about STSE. More broadly, the challenges describe indicate an opportunity or perhaps need for more support, time and training around the integration of non-traditional teaching practices – and although the instructors discussed a variety of teaching practices used, many instructors in the study still focus on highly traditional methods that may not elicit significant learning gains.

One problem with STSE – and the currents model – is that while the breadth opens up a diverse set of opportunities for exploration, the model begins to lose its meaning and over-arching goals. In examining STSE in the context of engineering, it would seem that a problem solving/design framework – given its significant to engineering – might be a reasonable place to introduce a broader set of STSE-related considerations and contexts, such as problems set in the context of socio-technical issues, and a more significant consideration of social and environmental impacts.

The study describes what STSE looks like in the context of undergraduate engineering education; and more broadly opens a dialogue about teaching practices in engineering, and bridges research and educational theory between K-12 and Post-Secondary Education. It is hoped that this may pave the way for further partnerships and inquiries in STEM education between the K-12 and post-secondary education, and open new opportunities for the sharing of pedagogy and perspectives across contexts.

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