



Real-World Examples and Sociotechnical Integration: What's the Connection?

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Introduction

In the U.S., engineers are often taught in ways that prioritize the technical aspects of problems while neglecting or deemphasizing any social considerations. Such privileging of the technical can lead to an inaccurate portrayal of the sociotechnical complexities of engineering problem solving in the workforce [1]. Engineering faculty frequently provide closed-ended, decontextualized technical problems to solve, which sends the message that social considerations are either irrelevant or of significantly lesser importance. Prior research has suggested that sociotechnical integration could benefit engineering students by allowing them to think more sociotechnically and better develop engineering habits of mind [2].

Sociotechnical integration refers to the integration of the social and technical dimensions of engineering problems [3]. Such an integration is integral to engineering work [1], but often not made visible in engineering education. Furthermore, sociotechnical thinking refers to ability to identify, address, and account for “the interplay between relevant social and technical factors in the problem to be solved” [2]. Thus, when applied to engineering education, sociotechnical integration involves pedagogies which identify and prioritize both the social and technical aspects of engineering problems in the classroom to better prepare students for engineering practice. The objective of such pedagogies is to enhance and improve students’ ability to think sociotechnically not just in current classes, but apply to engineering problems they run into in other courses and in the future. Since the terms “social” and “technical” are polysemic, we define them here. Social here is a broad umbrella term that encompasses economic, environmental, ethical, and health and safety considerations [4]. Of course, such considerations can also be technical, which accentuates the salience of the term sociotechnical. By technical, we refer in this paper to portions of problems that can be reduced to often-decontextualized smaller parts that are possible to solve in a closed fashion using mathematical tools

Multiple approaches exist for implementing sociotechnical integration within the American engineering education curriculum, as we will describe in this paper. This research paper seeks to explore one potential pedagogical approach: the use of real-world examples as a means of sociotechnical integration. Interest in this research focus emerged after research team members noticed the frequency with which students and faculty alike refer to the efficacy of real-world examples. Thus, this paper seeks to address the following questions:

- 1) What types and characteristics of real-world examples in engineering courses appear to facilitate sociotechnical thinking?
- 2) From the perspective of students, how can real-world examples more effectively promote sociotechnical thinking?

Real-world examples are potentially short in duration, making them an attractive and flexible course intervention strategy to allow students to further consider the social dimensions of engineering problems. This paper aims to map the prior work on real-world examples in engineering education and how these examples do or do not achieve sociotechnical integration.

Following a brief discussion of the background for this work, we define characteristics of and criteria for real-world examples and sociotechnical integration. Based on case studies from the literature and focus groups with students from our work on sociotechnical thinking, we then propose guidelines for the effective use of real-world examples in facilitating sociotechnical thinking, based on considerations such as class time required and course context. We hope such guidelines can contribute to bridging the gap—and accentuating connections—between the social and technical aspects of problems situated within engineering education.

Background

Most engineering curricula within the U.S. consist of highly technical coursework that is often decontextualized and separated from the social dimensions related to given problems [2][5]. While the ability to think analytically and solve closed-ended technical problems is a valuable skill, a sole focus on such problem-solving deprives students of an understanding of why social contexts matter to engineering success, such as valuing the creativity of diverse perspectives or taking into consideration the stakeholders who are affected by a technology [6]. In order to bridge the gap between the social and technical within undergraduate engineering curricula, sociotechnical integration within the classroom can be beneficial and encourage sociotechnical thinking.

Since sociotechnical thinking can be a highly abstract concept for some students, it is useful to ground it in terms of engineering habits of mind, which relate to the values, attitudes, and skills engineers value and possess [7]. The development of these habits of mind and sociotechnical thinking could influence how engineers act and perform in the workforce. Lucas and Hansen portray habits of mind as those that are “capable of development” via practice, repetition, and effort [8]. They list six different habits of mind for engineers: systems-thinking, problem finding, visualizing, improving, creative problem-solving, and adapting, all of which value both the social and the technical. Other research accentuates habits of mind in terms of systems thinking, innovation, adaptations and improvements, socio-cultural and ethical considerations, communication, collaboration, and sociotechnical integration [2]. Thus, the engineering habits of mind are instilled to improve students’ ability to develop professional problem-definition skills and to recognize the complex interplays between the social and technical dimensions when solving problems. In that sense, engineering habits of mind and sociotechnical thinking are interdependent variables: neglecting one generally involves the neglect of the other, and as one is strengthened, so is the other.

So which practices in the engineering curriculum can effectively further bridge the social-technical divide? Repeated practice and training in sociotechnical integration are critical, but which learning opportunities are most constructive and beneficial? One oft-cited pedagogical approach used by engineering faculty is a reliance of real-world examples to “tie material to future jobs” [9] and engage students with issues in the real-world. In part, the use of such examples is justified by arguments such as the fact that when engineering students graduate, they will be planted in real-world settings and conduct heterogenous work ranging from designs and models in construction, aviation, oil and gas, etc. Usually a problem about a residential wiring schematic of, say, a refrigerator or lightbulbs, would tend to resonate with students more than a random, decontextualized circuits problem with given parameters. These real-world examples

can be implemented in ways that range from brief mentions to full-semester projects. Such problem solving also prepares students for the realities of heterogeneous work in engineering practice [10][11]. Heterogeneous work has been defined as “simultaneously ‘social’ and ‘technical’” [12], “sociotechnical” [13], and work that “can never be separated from its social or political influences” [14]. Such problem solving also helps address a common ideology in engineering education, called technical-social dualism, wherein some try to draw firm but ultimately artificial lines between the social and technical dimensions of all engineering problems [15].

Due to the technical-heavy nature of engineering, intrinsic motivation can be a crucial reason for considering social aspects. A study implementing real-world examples in a basic electric circuits course investigated the difference in motivation of students in a course with real-world examples and one without such examples [9]. The study found that by employing real-world examples, students’ motivation increased because their course of study became more obviously relevant. Given such potential benefits, how can real-world examples be implemented in a way that effectively promotes sociotechnical integration and develops engineering habits of mind?

It is notable that there is relatively little empirical research investigating the efficacy of real-world examples in engineering classrooms. Furthermore, faculty often equate a real-world example with sociotechnical integration, but do not substantiate the tie between the two with concrete details. For example, in the circuits example provided above, there was likely no mention of who lives in the house, what the cost is of the electricity and the inhabitants’ capacity to pay for it, which appliances are used by whom and in which ways, etc. More often than not, the real-world example used fails to bridge the gap between the social and technical, much like the rest of the course that it is embedded within.

Criteria and Characteristics

Based on a review of the literature, “real-world examples” seems to be an approach to engineering education that is assumed to be understood by all rather than explicitly defined. For example, the National Academy of Engineering’s *Infusing Real World Experiences into Engineering Education* report [16] notably does not explicitly define what counts as a real-world engineering experience or program, despite its clear focus on such experiences. In this section, we highlight some of the definitions, criteria, and characteristics found in the literature which have informed the set of characteristics used in this paper.

Some discussions of real-world examples might imply that “real-world” necessitates connections to people in some explicit, direct or indirect way. For example, Huff writes that in his course, students, “Reflect on how real electrical systems interact with persons, and critique how these electrical systems affect social or environmental systems.” [17, p. 6]. In lieu of individual people, human organizations might be engaged, as suggested in the second course described by Subrahmanian and co-authors, which grounds real-world projects in local governments and industry [18]. The modules described in Mousavinezhad et al., “showcase how engineers impact society” [19, p. 4]. It is unclear if the societal impact on engineering is also illuminated by the modules. This question is expanded in [20], which notes that since technology is often viewed as

asocial, engineering work is often seen as outside of society, an idea that aligns with technical-social dualism [15].

Another common suggestion is that the engineering design process may be key to the definition. Subrahmanian and co-authors indicate that “real world” is related to the problem formulation step of the design process [18]. In another study, the “planning and decision making” portions of the design process are emphasized in the learning objectives for the real-world computer simulation described in [21, p. 332]. Other objectives include budgetary and time constraints, teamwork, and “large industrial-scale chemical processes” [21, p. 332]. Professional standards are one element of the real-world examples discussed in [22].

Career preparation is another common element in papers describing real-world activities. “Real-world examples tie material to future jobs,” writes Campbell [23, p. 3]. The fact that “all four senior student interns received engineering job offers before graduation” was noted as an outcome of the solar charging design project described in [24]. Bridging the gap between theoretical and practical knowledge, where presumably practical knowledge is the type needed in the workplace, is the intent of real-world problem solving, as described in [25].

Dunsmore, Turns, and Yellin [26] examine real-world examples from the student perspective. They report diverse student conceptions of “real-world” issues, but not necessarily real-world examples. They report that mechanical engineering (ME) students conceived of engineers in the workplace as leaders due to their “competence in the world of theory, design, ideas, and creativity” [26, p. 336]. The “real world” of manufacturing conflicts with this world of engineers’ “brilliance” because the real world is limited by such factors as machinery, real-world tolerances, costs, and time constraints that can lead to difficulties and mistakes. In this study, students reframed such difficulties by stating that through “teamwork, collaboration, and communication, engineers can overcome the real-world aspects of feasibility, constraints, and hands-on manufacturing” [26, p. 336]. This student perspective illuminates the fact that the message students receive about the real-world may be that it differs from a purist or technocentric image of engineering marked exclusively by a focus on technical instrumentalism [12][13]. Another study of student perspectives is described in [9], which summarizes the student interpretations of the meanings of “real-world” as 1) when ‘real-world’ problems engage and show the relevance of previously learned math and physics content, 2) when such problems help students understand course content better, and 3) when such problems help students select future elective courses and/or better understand the nature and scope of industry problems.

The time scale over which the “real-world” elements are introduced may also matter. A real-world *example* might be investigated over the course of a single class, whereas a real-world *project* or *problem* might take place over weeks or months. The library of real-world engineering project modules described in [19] are intended to last for about two weeks, facilitating integration into existing courses. The sociotechnical integration described in [20] covers a full course. The “sequenced set of experiences” in [27] “was designed so that students would engage with communities to better understand the complex social, technical, and environmental risks that miners confront and then propose and, in some cases, develop projects to reduce those risks” [27, p. 3], and entails multiple semesters, though the same students are not necessarily engaged across the full-time frame. This substantial project is intended to overcome technical

instrumentalism, the idea that technical skills alone can address any problem, which emerges from the broader ideology of technical-social dualism [14][15]. Finally, the National Academy of Engineering's *Infusing Real World Experiences into Engineering Education* report covers experiences ranging from short, in-class projects to programs which might span multiple years of an undergraduate degree [16]. In summary, real world elements in engineering classrooms may vary in goal (e.g., connections to people, career preparation, design skills) and duration (short term examples to longer-term projects). However, they are rarely defined explicitly.

For the purposes of this paper, we have focused on real-world examples with the following characteristics:

- Their duration can range from just a few minutes in one class to spanning multiple class periods (typically just one or two). A real-world example is smaller in scope than a project-based learning experience, which also relies on authentic problems.
- They are conveyed by the course instructor during class time. Alternatively, they might be introduced outside of class (via assigned readings, videos, etc.), but are incorporated into the standard mode of instruction in some way – for example, through in-class discussions or active learning activities.
- They are included in a course for a range of reasons, including to increase student motivation or prepare them for their future careers.

By contrast, sociotechnical integration is a less common term and thus more likely to be defined and explained in detail. Cohen et al. describe how a “new course, taught within the structure of a required ‘Introduction to Engineering’ framework, develops a socio-technical concept of technology as a system and engineering as a multi-faceted (not strictly technical) activity” [20, p. 1]. This perspective aligns with the challenge to technical instrumentalism described in Reddy and Lucena [27]. Mogul, Tomblin, and Reedy highlight contextualization as a key element of sociotechnical integration, explaining that real problems are not decontextualized but render visible the social context in which the engineering problem resides [28]. The authors report that students convey varied views, ranging from ardent defenses of decontextualized problems to saying that such problems are misleading and incomplete. In previous work on social justice in engineering education, the distinction between closed-ended and open-ended problems was one key to effective social justice integration into an engineering course, along with repetition of the social justice concepts throughout the semester [29]. Whereas closed-ended problems generally have one correct answer, open-ended ones have multiple possible responses.

Based on this assessment of the literature, we propose the following characteristics of sociotechnical integration into engineering curricula. Sociotechnical integration...

- Must illuminate the complex interplays between people (communities, etc.) and the technical side of engineering. It is not limited to looking at how engineering technologies impact society, but also includes how society impacts engineering problem definition and solutions.
- Must be explicit. As we stated above, all engineering work in practice is implicitly sociotechnical. However, when this work is presented in courses, the connection is often not clearly made for students.
- Must be contextualized. It is impossible to achieve sociotechnical integration without an understanding of the socio-cultural context of the problem.

- Generally relies on open-ended problems, allowing students to experience tradeoffs in engineering processes.

It is important to note that we are speaking of implementation of real-world examples into engineering curricula and recognize that some classes may be taught in formats other than a lecture-based course. Some examples of this could be inverted or flipped classes, active learning, laboratory courses, project-based courses, or discussion-based courses. While classroom implementation may vary, the use of real-world examples as a means of sociotechnical integration can likely be adapted to most course formats. We propose that most engineering courses, no matter the format, can use real-world examples associated with the class to promote engineering habits of mind and further improve students' sociotechnical thinking.

Case Studies of Real-World Examples With and Without Explicit Sociotechnical Context

To illustrate the difference between real-world examples which do and do not include sociotechnical context, we looked to the literature for cases that align with the criteria and characteristics outlined in the previous section. Here the focus is on one case of real-world examples without their sociotechnical context and one case which included sociotechnical integration.

To qualify as a potential case study, the work had to be published in a peer-review conference or journal paper. The paper needed to provide sufficient details about the examples and their use within the context of the course so that conclusions could be drawn about their efficacy. Furthermore, we eliminated cases where the inclusion of the real-world example was a work-in-progress [17] in favor of more established and well-assessed interventions. We looked for cases where the examples were integrated into a discipline-based technical course. This ruled out, for example, stand-alone engineering ethics courses [28]. As mentioned in our *Criteria and Characteristics* section, we are interested in real-world examples which are of a shorter duration than project-based learning, where sociotechnical integration can sometimes be meaningfully achieved [27][29][30]. Finally, we selected our two case studies based on what we saw as exemplary uses of real-world examples, one with and one without explicit sociotechnical integration. We wanted examples that would be understandable, relatable, and impactful. We decided to not include cases where the references to real-world examples lacked specificity [22] or were focused on advanced examples like current faculty research projects [9].

Use of real-world examples without sociotechnical integration

As an exemplary use of real-world examples, we selected Nilsson's work using Everyday Examples in Engineering (E³) to engage students in her sophomore-level Mechanics of Materials course at Santa Clara University [31]. Nilsson set out to present course content through examples that students were familiar with in their everyday lives, rather than via applications that they might have had very little personal experience with. She utilized E³ developed by other researchers through a National Science Foundation-funded research project, ENGAGE [32] [33].

One of the most impactful E³ that Nilsson used was to illustrate axial loading and deformation of composite members. When teaching this topic, faculty and textbooks often cite the example of a

concrete/steel composite column. Nilsson points out that most college sophomores typically have very little personal experience with the construction and behavior of such columns. Instead, she used earbud-style cable headphones as an E³ to demonstrate the behavior of composite materials. Students could easily relate to cases where the cable could be used to “catch” a falling electronic device like a smart phone, thus being axially loaded.

Nilsson rigorously assessed the impacts of the E³s in her classroom through final exams to measure understanding, pop quizzes in a follow-up course to measure long-term retention, and an end-of-term survey in order to measure student interest. She compared results between three semesters of the course which did not include E³s and five which did.

Nilsson’s work found that the E³s had the greatest impact on student performance on exams when used for concepts which students had historically found challenging. Results also show that long-term retention of learning improved for all topics, including ones where student exam performance was traditionally satisfactory. Finally, she reported that student interest in course material increased slightly for male students following the implementation of E³s, but significantly for female students. She cites this as an important finding since interest in a topic has been correlated with students’ self-efficacy, which in turn relates to persistence rates in engineering, a field which fails to retain female students at the same rates as male students [34].

Use of real-world examples with sociotechnical integration

During our search of the literature, the work of Andrade and Tomblim emerged as a case study on the use of real-world examples with explicit sociotechnical integration [35][36]. In their 2018 paper, Andrade and Tomblim describe efforts to incorporate social dimensions into a technical course, Engineering for Sustainability [35]. They focus specifically on three in-class activities that emphasize a sociotechnical systems framework and stakeholder value mapping. To varying degrees, all three activities included group activities, readings either before or during class, and follow-up questions (through worksheets or online quizzes). Each activity was focused on a different sociotechnical topic: ethanol-from-biomass production; wind farms; and electric and autonomous vehicles (EV/AVs). The first and second were focused on single class sessions, and the third activity spanned two class sessions.

In the ethanol and wind activities, students more easily identified economic and environmental impacts than social impacts [35]. Any social references were “rare and superficial” [35, p. 8]. (Andrade and Tomblim focused on the United Nations’ definition of sustainability, which is composed of three dimensions: social, economic, and environmental [37]. Though they do not explicitly define what counts as a “social” impact, the authors seem to be using a definition that differentiates it from economic and environmental concerns. This is different from other studies, including ours, which use “social” as an umbrella term for dimensions of engineering problem solving such as economic, environmental, ethical, and health and safety [4].) Because of their findings from the first two class activities, the Andrade and Tomblim decided to focus most of their analysis on the third activity on EV/AVs, which was developed after realizing that students struggled to identify social impacts in the first two activities. Through this activity, they found that students did develop a (slightly) deeper understanding of what social impacts are and were more aware of second-order social impacts. The authors define second-order thinking as,

“identifying and establishing indirect connections and consequences beyond direct cause and effect relationships of technologies and technological artifacts and thinking about the social consequences of technology beyond productivity and efficiency” [36, p. 3]. They point out, however, that all three activities did result in evidence of deepening students’ understandings of sociotechnical complexity in engineering (not just the third and final one).

Andrade and Tomblim’s follow-on work used both thematic and open coding to look at student written responses following the EV/AV activity more deeply, with a specific emphasis on understanding the instrumental and non-instrumental constructs students use in discussing sociotechnical systems [36]. The authors define instrumental thinking as a “narrow view of how humans impact technology and how technology can impact humans.” (Note that Andrade and Tomblim’s term “instrumental thinking” is synonymous with another term, “technical instrumentalism,” which we described in the *Criteria and Characteristics* section above.) Instrumental thinking assumes that technology is value-free and reflects “first-order sociotechnical thinking, in which social relationships with technology are defined in terms of efficiency and productivity outcomes” only. Andrade and Tomblim found that students made references to seven common themes with regard to social, political, and economic issues surrounding electric and autonomous vehicles. Examples of these themes included *Quality of Life, Infrastructure Design, and Consumer Impact*. They found that most of these themes were dominated by instrumental thinking which, interestingly, was not emphasized in the readings, activities, or lectures. Thus, students were drawing upon “common over-simplified models of how the social world works and how the public interacts with technology” [36, p. 9]. When they did move away from instrumental thinking, they tended to draw from specific examples of non-instrumental thinking that were provided by the instructor through the readings and in-class activities. They struggled to move beyond these scenarios and to adopt the perspectives of stakeholders who were very different from themselves.

Case Study Discussion

From comparing these two case studies, a few interesting observations emerge. First, it is not surprising that the sociotechnical case study took place in a sustainability course. The authors repeatedly state that the course is “technical,” but it is possible that this course topic might lend itself to a more natural integration of sociotechnical considerations than, for example, a feedback control systems course [29].

Andrade and Tomblim point out an interesting and important limitation of their study: they acknowledge that sociotechnical thinking is complex and is likely influenced by multiple factors, including those beyond the content taught in a specific course. This *a priori* knowledge contrasts, for example, with calculations of the moduli of elasticity that are taught in a *Mechanics of Materials* course [31]. Thus, it is difficult to say that one course impacted students’ understanding of sociotechnical issues, much less a single classroom intervention. It is possible and very likely that other influences – other courses, life experiences, and social interactions – also impact students’ sociotechnical views here.

Finally, it is difficult to achieve complex sociotechnical integration – especially that which moves beyond economic and environmental considerations in order to elicit second-order

sociotechnical thinking [36] – in a limited amount of time. By necessity, real-world examples with effective sociotechnical integration take time to convey information, present diverse perspectives, and allow the students to process and discuss. Andrade and Tomblim’s work took four classes, which, depending on the course schedule, might be considered too long by some faculty members.

Focus Group Methods

For student perspectives on the characteristics of effective sociotechnical integration (our second research question), we draw from focus group data obtained from students enrolled in two classes at the Colorado School of Mines, a public, engineering-focused university in the western U.S. The semi-structured focus group questions appear in the Appendix. All data was obtained and analyzed via our institution’s IRB-approved processes.

The method for focus group (FG) data analysis involved a streamlined codes-to-theory model for qualitative inquiry [38]. A key advantage of this model is that any theme to emerge from a FG can be clearly traced back to specific student statements.

To paraphrase another researcher, codes produce the bones in the data analysis process, and categories help to create a more coherent skeleton [39]. Thus, FG data analysis leads to codes, research-question-relevant categories, and broader themes. Those themes in turn lead to overarching, summative theories or assertions about the data, as depicted in [38, Fig. 1.1]. To extend the anatomical metaphor, themes are statements that describe how key components of the skeleton fit together, and theories or assertions depict how the skeleton is likely to function as an integrated whole. The data-code-category-theme-theory model moves from relatively concrete to abstract and involves a highly iterative process of refining, with much cycling back and forth to reconsider relationships among codes, categories, and themes [38].

The first phase in the process involved open and *a priori* coding. Open coding involved noting any phrase or idea that helps capture how students conceptualize, however broadly, their own undergraduate engineering education or anticipated life beyond that education. For instance, transcript passages could be coded topically as “engineering work,” “engineering workplace,” or “engineering practice” and other codes inspired by the data by each member of the research team. Further analysis could place such codes into related categories; in this case, one researcher identified the category, “Constructing the Engineer.” Analysis of the context in which students discussed how they construct the work of engineers led to the theme, “Connecting current to future learning,” and eventually to the finding that students see real-world problems as a bridge between the engineering curriculum and engineering practice.

To check potential sources of researcher bias, multiple researchers (a minimum of two) conducted separate analyses and reported their findings in individual analytic research memos, which included themes and assertions, as defined by Saldana [38], for each focus group. These findings were often substantiated with direct student quotes. Then our research team met to negotiate these individual memos and co-write a consensus memo. In these memos, the word consensus does not mean researchers agree on a single interpretation; instead, when applicable they explicitly include points in which we interpreted or categorized data differently. Also, in

some cases, researchers who have coded previous transcripts sometimes skip the coding process and place student statements directly into a category or theme. In this study, two researchers wrote separate analytic research memos for the pair of focus groups for each course, combining themes with substantiating quotes from each FG. Two additional researchers also read the same FG transcripts and consulted on the writing of the consensus memos. Thus, four members of the research team consulted on each consensus memo for the two courses.

A priori categories were established by previous literature, focusing on how students integrate social and technical bodies of knowledge [6], how they engage habits of mind [7], and how they discuss sociotechnical engineering [15], [40]. The courses and 19 participant pseudonyms appear in Table 1.

Table 1: Spring 2019 Focus groups in two engineering courses. Students were invited to select their own non-identifying pseudonyms.

Course	Focus Group #	Participant Pseudonym	Participants
Intro to ME	01	Bob, Brian, Cleopatra, Dakota, Pete, and Sheila	6
Intro to ME	02	Colson, Grace, Kai, and Seven	4
Electromagnetism	03	Cheddar, Pepperjack, Mozzarella, and Swiss	4
Electromagnetism	04	Ponyboy, Krump, Johnathan, John, and Spencer	5
Total			19

As seen in Table 1, Spring 2019 FG data came from four FGs across two engineering courses, a sophomore-level introductory mechanical engineering course (Intro to ME) and a junior-level course on engineering electromagnetism (Electromagnetism) typically taken by students majoring in electrical engineering. Student perspectives emerged on the challenges associated with working to solve real-world problems, which facilitated diverse forms of sociotechnical thinking. Data are reported here based on the context in which such real-world problem solving was described, with special attention to descriptions of how real-world examples were employed in courses. We include data from both courses when applicable.

Analyzing engineering student descriptions of real-world engineering problem solving when they generally have not yet had extensive hands-on experiences solving such problems raises some issues. Students are conjecturing. However, from those conjectures, we learn how students construct the actual realm of engineering practice and how it is communicated to them by their professors and other experts. In so doing, we gain additional insight into what students do and do not value in the engineering curriculum, and why.

Focus Group Findings

We organize this description of our FG findings according to the three categories that emerged using the methods described in the previous section:

- Real-World Examples in the Engineering Course
- Real-World Examples in the Engineering Curriculum

- Real-World Examples as a Bridge Between Engineering Curriculum and Engineering Practice

Real-world examples in the engineering course

Inside the context of Intro to ME and Electromagnetism, students identified what they considered to be real-world problem solving that involved or fostered sociotechnical thinking. In some cases, students also commented on how some activities did not foster such thinking.

In Intro to ME, students were presented with design issues associated with U.S. currency. Unlike bills from other countries, U.S. bills are all the same size regardless of denomination. This presents difficulty for visually impaired individuals to distinguish, for instance, a \$1 from a \$100 bill. In FG02, Grace noted that engineers who are not visually impaired may be unlikely to consider such a design flaw, and that accentuated for her the value of stakeholder engagement: “How does the normal person get feedback to the engineer...? ... I can see how it can be hard to read that bill, but I'm not blind, [so] I have no idea” (01:07:40). In FG01, Sheila said that the U.S. currency example made her realize how unfair the design is for visually impaired and blind people, and “just by learning that one thing really opened my eyes to seeing problems with other things in society that engineers have kinda singled in on one group” (00:32:39). In these cases, we see that the use of a real-world example with specific sociotechnical elements served to develop specific habits of mind in the students, like valuing stakeholder engagement and considering multiple, diverse users.

Cleopatra in FG01 said she found a sociotechnically-motivated interview assignment (see [41] for details on the assignment) valuable for emphasizing elements of real-world problem solving. She spoke of a friend who is “a civil engineer [with] a really difficult task ahead of them and they have to look at the big picture to think of a different solution when the problem seems kind of unsolvable, and it's just constant teamwork and thinking about things in different ways” (00:17:33).

In Electromagnetism, FG participants identified several real-world problems that facilitated sociotechnical thinking. These electromagnetics problems were, according to FG participants, effectively framed by the Grand Challenges of Engineering (GCE), which were presented in the course. For instance, in FG03, Cheddar said that

The key focus is to address each [of the selected GCE] individually and kind of not only learn the subject matter associated with it but also understand why it's important or what societal impacts it has; so even though [the instructor] never typically said socio-technical engineering, it's kind of just emerged itself in there, so it's a part of it, regardless of whether we are aware of it or not. (37:09)

The Grand Challenges were introduced primarily to leverage this pre-defined list of important engineering problems that currently exist within the real-world. In the focus groups, the students recalled many of the specific real-world examples that stemmed from discussions of the broadly-defined Grand Challenges. For instance, they mentioned electronic ink (E-ink), radiation from

cell phones, lab on a chip, and other real-world problems catalyzing a better understanding of sociotechnical thinking, both at simplistic and more complex levels. For instance:

FG03, Mozzarella: 01:18 It's kind of a well-rounded class and [the instructor] definitely makes an effort to tie in different engineering challenges, so you get a lot more real-world applications. For example, we just talked about the solar panels in our little wave unit and on my spring break trip, we drove past a massive solar farm and it was kind of cool because it was like, "Hey, she's talked about those." I have a much better understanding of the actual use of these now. I'd say it seems really more useful, 'cause it's helped a) in other classes and b) when I walk around, I see stuff that applies to the class.

FG03, Cheddar: 13:37... I think when I hear "socio-technical engineering," I think of understanding that the things that we, as engineers create, even though we design it for a certain purpose, we also have to take into [account] the aspect that they could be used for other means, whether they're productive or they're malicious.... That every decision we make and everything we create has a consequence towards society and towards the people that we make it for and we have to take that into consideration.

FG04, Johnathan: 33:55 Lab on a chip. And the idea to compose technology things like processing someone's blood for ... blood tests on ... [the] order of cents per test, and days instead of like months. And no mailing it and stuff. And so we talked about all the impacts of [lab on a chip].... There were questions brought up of like maybe instant feedback on medical tests isn't the best thing, especially [when] ... the culture of medicine is very different, and maybe like in a household having that information immediately is not great.

Furthermore, FG participants accentuated how exposure to multiple real-world problems in Electromagnetism helped them understand why stakeholders are part of the sociotechnical thinking process. Stakeholder involvement and degree of agency in shaping technology became apparent after they asked particular questions, some of which introduced additional complexities:

FG04, Ponyboy: 35:20 We always ... ask the three questions, like who's like affected, like who does this benefit, like who does this not benefit, and ... who doesn't have a say, or something like that. And ... it kind of struck me because it's kind of like that's not fair. Like how do we have the right to say who doesn't have a say in this technology? So ... I guess I really never delved into that fact that sometimes we design technology kind of like without people's ... Like this specific group of people can't have a say in what we're doing.

FG04, Johnathan: 36:50 The big thing that I hadn't considered before is the idea of considering those who aren't, like, directly impacted, or just like always trying to take the time to think about the people that have no sort of say in what you're doing.

Generally, students appreciated the opportunity to consistently practice real-world sociotechnical thinking throughout the course on assignments, discussions, and exams, which they indicated was missing from their other technical coursework.

FG03, Mozzarella: 36:11 We have a question on every test. It's like, how would this adversely affect, you know, whatever and so it's like before the test, I'm thinking okay, we even talked about this topic all semester long. What are the [drawbacks] ... for this given technology.

FG03, Mozzarella: 41:37 [The instructor] has given [Electromagnetism students] opportunities to practice. Kind of, practice makes perfect. I don't feel like I need a class that should sit me down and tell me that I need to look for these 10 things but more that gives you the opportunity to think about [it] yourself, [and] learn, that way.

One student considered the real-world problems that facilitated sociotechnical thinking to be quite valuable, and said it could be integrated in every course.

FG04, Johnathan: 47:51 I think it's at least important to have students consider [sociotechnical engineering] in every class. Maybe not like spending a whole lecture talking about how something can be applied, although I would personally like that. But just making sure that every step there's at least some sort of aspect of the course that lets us consider different pieces of it. Because then that helps you become motivated to study things more, or realize that maybe you want to pursue something more... It just makes it more interesting and it's important to always keep that consideration, I think so.

Many of the comments in the section above from Electromagnetism FG participants accentuate both real-world examples in the Electromagnetism classroom as well as how those can or do apply to real-world problems in industry/engineering workplace contexts. Notably, mostly junior-level students in Electromagnetism made far more connections between real-world problems in that course and sociotechnical thinking than mostly sophomore-level students in Intro to ME. This issue is further addressed in the conclusion of the paper.

Real-world examples in the engineering curriculum

In addition to observing the utility of real-world examples within specifically the Intro to ME and Electromagnetism courses, students also identified how real-world problem solving occurred in other courses in the engineering curriculum. Because these other courses were not part of our research study, we have fewer details about implementation of the real-world examples but can still learn from student remarks. In terms of required core courses, students focused on a first-year, cornerstone design course, a first-year humanities course, a first-year hybrid (design and humanities) course, and a second-year required social sciences course. In Electromagnetism, students also mentioned two upper-division courses.

Students in FG02 from the Intro to ME class emphasized how technical and non-technical bodies of knowledge can intersect. For instance, Grace said that she now realizes the importance of identifying stakeholders with key non-technical bodies of knowledge because of the real-world experience gained in her cornerstone design course: "...we had to make a large-scale composter, and I think we interviewed the wrong people. We weren't really guided as to who the stakeholders were..., and in hindsight we probably should have interviewed restaurants and

grocery stores, but instead we interviewed people that had composters and stuff” (00:11:23). Exposure to the importance of diverse stakeholder forms of knowledge—via design courses—was a theme that ran through many student comments.

Generally, students indicated that they viewed the bulk of the engineering curriculum that they had experienced as sterile and removed from hands-on, real-world engineering problems. They also identified what they saw as critical gaps in their engineering education, such as the fact that while environmental issues are discussed in environmental courses, they are not sufficiently emphasized in design courses. From such statements, it became clear that some students would prefer to learn about social and environmental responsibility within the context of real-world problems. However, so far, they indicated that the curriculum provided little of such content.

In terms of the role of sociotechnical engineering in the curriculum, perspectives varied widely. Bob in FG01 initially said of sociotechnical engineering, “It'd be pointless to teach anything else, 'cause if you're gonna design something without considering, I guess, the end user, what kind of effects would have; there's no point in the design, really. So, I'd say it's just as important as teaching the technical aspects” (00:38:35). However, he went on to respond to others’ comments by saying, “I do agree it doesn't need to be taught in every class, 'cause once you get it, you get it.” Other participants said that while the sociotechnical engineering content is necessary, it is difficult to integrate in a standard engineering curriculum, as elaborated below.

Focus group participants in Electromagnetism focused on three required core courses and two upper-division electrical engineering courses. Their comments focused on real-world examples that facilitated an understanding of how, in various ways, social and technical dimensions of problems interact.

For example, in FG03, Pepper Jack expressed a general appreciation for the classes that teach the ethical dimensions behind engineering, including “some of the pitfalls of previous engineers and previous kinds of disasters that you can learn from and then in classes in the future, where you can kind of practice applying the socio-technical engineering” (42:51).

Students clearly placed value on real-world examples across the engineering curriculum, as in this statement from FG04:

Ponyboy: 48:36 I liked ... especially like in classes throughout my years at Mines, I just found it really interesting like when the professor gave like real-life examples. Like we're studying something and it's like oh, this is what this does in today's world, and it's like, "Oh, okay!" And so it's cool to like, when you like go outside and you're walking around you're like, you actually know like the science behind it. Because like before it kind of just like that just does something. Like you're driving down the road like, "Oh, like these wires help me be able to call my grandma across the United States of America." But it's like that's ... very top level, but it's kind of cool to get the gist of it and like we'll actually have more information about this thing that you really actually know how this works, you know?

From these examples in both courses, it appears that these students thought that real-world examples in the curriculum taught them a range of sociotechnical thinking skills, with lessons about ethical, social, and environmental responsibility and stakeholder engagement, including the importance of social and technical bodies of knowledge and how such perspectives can intersect. Generally, they valued real-world examples as useful for understanding how designs affect people, and how mechanical or electrical systems enable everyday behaviors that we might take for granted.

Real-world examples as a bridge between engineering curriculum and engineering practice

Because most have not worked as engineers, engineering students' knowledge of engineering practice is largely theoretical and from second-hand sources. In their current stage of development, students perceived a disconnect between their perceptions of what their education should emphasize and what their future as practicing engineers will involve. They implied that real-world problems can serve as a bridge between the engineering curriculum and engineering practice. Interestingly, students seemed to value technical knowledge in undergraduate engineering education, yet they also show a strong valuation for sociotechnical knowledge in engineering practice.

Students appreciated how their curriculum had highlighted the sociotechnical nature of real-world engineering problems. For instance, they identified their first-year design course that gave them insights that are generalizable across all design contexts, such as the fact that empathy is crucial to effective user-centered designs. In fact, in FG01, Cleopatra, (with Sheila and Bob agreeing) said design classes make them feel most like an engineer: "the design classes, like [first-year design] and [Intro ME], make me feel the most like an engineer" (24:37). "It's fun," Bob added, due to the challenge of solving open-ended, complex problems. In FG02, Kai emphasized the three traits that "go into [her] considering [herself] having traits of an engineer," ones that "impact the work that I do and how I work with others:" traits of "empathy, responsibility, and collaboration" (00:30:21).

Kai in FG02 seemed to place the fault of the disconnect between engineering education and practice on engineering education itself. She described her studies as, "There's not really a bigger picture, ... you have a goal to complete, you complete your goal, you study for the test, you repeat. And you learn things, but a lot of the time you can't really connect 100% what you're learning to how it's going to be useful, how you can use it in the future" (00:57:47). In short, the lack of sociotechnical context in curricular problems constitutes, in some students' view, an inaccurate reflection of industry realities. This became clear in the responses that followed from two other students in the focus group after Kai's statement above:

Grace: 00:58:30 I agree, I feel like they're giving us more of a process. Group activities, yeah that's super important to work in industry, but it's more just like going through the steps, it's not really making me feel like I'm doing anything that an engineer would do. Obviously the practice is important, but I feel like the...what I'm trying to say...the bulk of it's not there.

Colson: 01:00:30 I think one of the big things is that, in the classroom setting, most of the time it's like the financial side of things isn't considered... In my [mining engineering] class, for our testing, we've talked about the financial side of things, and we're using something like \$50,000 worth of recording equipment for every time we test, that's why we gotta make sure we get everything right, don't destroy things, and then, if something does happen, what do you do then?

Despite seeing sociotechnical context in engineering problems as a missing component in their education, other students said integrating sociotechnical engineering is fraught with complexities. First, many students see sociotechnical engineering concepts as far less important than technical information, as technical information guides engineering decision making. Not all agreed, however. In FG01, Bob indicated (and Pete agreed) that both are intertwined: "I'd say [sociotechnical engineering is] just as important as teaching the technical aspects" (00:38:34), even if it is, he added, not necessary to reinforce sociotechnical thinking in every course.

Many students saw the teaching of sociotechnical engineering as important but either quite difficult or impossible given the constraints of academic structures. For instance, in FG02, Seven said,

But I'm beginning to wonder if trying to teach [sociotechnical engineering concepts] in the academic structure itself are almost at odds with each other on a fundamental level, because I think the sociotechnical engineering you learn by trying to work on a project and make it work in the real world with real people with real constraints and real money; and trying to fit that into a classroom, I think it's important and noble, but I think all of my previous statements can be summed up with, I think it's very difficult to fit sociotechnical engineering into the classroom. (00:35:34)

For many students, real-world engineering problems fostered reflection on approaches to applying engineering knowledge after graduation. Notably, students suggested that classes were relevant or useful if they related directly to what students intend to study or go into in their post-baccalaureate careers, as in this statement from FG04:

Krump: 01:39 I feel like the fact that [Electromagnetism] expands on Physics 2, like really expands into E&M (electricity and magnetism) and their wave components and how, especially in this class, where real-world applications are actually discussed and how E&M relates to these real-world applications. I think that connection makes this class pretty important.

With that, if a class feels 'useless' or 'irrelevant,' students may feel less like an engineer because the course may foster an attitude inconsistent with their goals or values, as in the discussion below in FG03. In this excerpt, students imply that the problem-solving values they are developing in undergraduate engineering will carry over into their careers.

Cheddar: 31:12 So just based on my personal values, there is an incentive to be conscientious of everything that I design. I think for some reason, that's the first thing that comes to mind whenever I look at a problem, is if it's something that I need to design for

the greatest amount of good for the greatest amount of people or something that's designed just for one customer. What are the impacts of that and also kind of take into account the standard lead time. How fast do they need the solution and how critical is it for these people to have that solution because then am I willing to sacrifice, I guess, personal time.

Mozzarella: 32:20 I know for me, a very motivating value in a lot of my things is kind of pride, like with my homework and with anything, I'm going to put in, I want to be able to say, "Oh, yeah. I did that," so I know when doing work or designing a solution, it's like, there might be an easier way that I could half-ass it or I can do this right and 99.9% of the time, it's, I want to do this right. I want to understand it or I want to be able to say, "Hey, I designed this." Like show my friends. So it's kind of like desire to take ownership of what I'm doing, so I don't really take the shortcuts.

Similar discussion emerged in the other FG, in which for instance, Johnathan, when asked to explain the meaning of sociotechnical engineering, said, "It's engineering with more purpose behind it, rather than 'I want to solve this interesting problem.' I'm going to solve it. ... there's a need to solve this problem. I'm going to solve it in a way that fulfills that need and doesn't create [new] problems" (10:47).

Suggestions

Based on our review of the literature on real-world examples and sociotechnical integration and the focus group data reported above, we outline below a comparison of real-world examples as they are typically introduced into an engineering classroom and with suggested modifications to promote sociotechnical thinking into such examples and potential outcomes.

Table 2: Real-World Examples with Sociotechnical Integration Suggestions

	<i>Real-World Examples</i>	<i>... With Sociotechnical Integration</i>
<i>Content or topic</i>	Technical, mathematical relationships or concepts drawn from real-world contexts	... Explicitly presented with clear and relatable social context, perhaps through stakeholder interviews, readings, in-class discussions, etc.
<i>Desired learning outcomes</i>	Improved exam performance, increased retention, increased engagement/interest in the material [31]	... Deeper learning with improved future recall. Increased alignment with engineering practice [1].
<i>Other potential positive outcomes</i>	Increased self-efficacy, improved outcomes for female students [31]	... Potential for increased attention towards social responsibility and social justice considerations and engagement of underrepresented engineering students.
<i>Use within the classroom</i>	Examples during lecture and experiential examples (items that students can hold and manipulate) [31]	... With in-class discussion, problem rewrites [29], interview assignment [41].
<i>Learning assessments</i>	Decontextualized homework problems and exams	... Homework problems, projects, and exams with sociotechnical context.

Drawbacks or tradeoffs

Time required that takes away from other tasks [22]

Time required that takes away from other tasks. It often takes much more time to do proper sociotechnical integration than to include a simple reference to a real-world example.

Most professors haven't been trained in this manner, and thus may feel like they lack the required confidence or knowledge.

Conclusions

Sociotechnical thinking is an important skill that can contribute to preparing engineering students for their future careers. In order to facilitate that, we propose that engineering education should strive to implement more sociotechnical integration into courses in order to allow students to not only think in the technical dimension but also the social. Real-world examples and problems are just one way that sociotechnical integration can be implemented in order to have students more engaged in their coursework while also preparing them for beyond the classroom.

Real-world examples are often touted in engineering education as an effective pedagogical technique. However, they have not been extensively and specifically studied as an effective intervention. As mentioned before, real-world scenarios can come in the forms of simple examples that last a few minutes to extensive projects that last months. In this paper, we examine whether or not they can be an effective form of sociotechnical integration within classrooms. As one of the case studies presents, sociotechnical integration is complex, so there are various factors that may affect student views of such pedagogical approaches, and no form of it may be 'perfect' per say.

Focus group data clearly indicates that the primarily junior-level students in Electromagnetism made far more connections between real-world problems in that course and sociotechnical thinking than the mostly sophomore-level students in Introduction to Mechanical Engineering. This issue merits further research to determine the reasons for that difference—whether the factors are developmental (juniors may be at higher cognitive levels than sophomores), curricular (due to exposure to a greater overall percentage of the engineering curriculum), course-specific (related to the quality and quantity of sociotechnical information students integrated into graded problem solving), other factors, and/or some combination of some or all of the above factors. Overall, students appear to recognize the value of sociotechnical thinking while considering real-world examples to further that value.

Sociotechnical integration incorporated with real-world examples are less frequently described in the literature due to the complex nature of it. This type of integration requires extensive amounts of preparation and execution, making it perhaps difficult to generalize across different courses, instructors, and students. Though real-world examples are frequently perceived as easy to integrate into courses in a short amount of time, real-world examples with sociotechnical integration often require far more time and effort. Though it appears from our focus group data that real-world examples tend to stick in students' minds, effective sociotechnical integration requires more than just a simple mention as is commonly the case of real-world examples.

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Appendix: Focus Group Questions

1. What score on a scale from 1 to 100 with 100 being the most useful undergraduate course and 1 being the least useful undergraduate course: How would you score this course?
 - a. Tell us more about what impacts that score? (What elements of the course did you consider when determining that score?)
2. Have you heard the phrase “sociotechnical engineering” previously?
 - a. Have you heard it in the context of (GEEN1400/MEGN200/EENG386)? What about your other engineering classes?
 - b. What does it mean to you?
3. Tell me some words or phrases that describe what you think practicing engineers do, think, and believe.
4. Do you identify as an engineer? Why or why not?
5. What values or attitudes do you hold that influence your identity or lack of identity as an engineer?
6. What did you learn in your (GEEN1400/MEGN200/EENG386) course, which you did not previously know, regarding sociotechnical elements of engineering?
7. How did your (GEEN1400/MEGN200/EENG386) instructor convey the concept of sociotechnical engineering?
 - a. What could your instructor have done to better prepare you as an engineer to consider sociotechnical elements of engineering?
8. How appropriate is it for engineering professors to teach sociotechnical concepts in technical engineering courses?
9. How appropriate is it for practicing engineers to consider sociotechnical concepts when designing engineering solutions?