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Talking Tech: How Language Variety in Engineering Curriculum Instruction Can Ease Delivery and Engage Students

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Abstract

Background: As accreditation bodies globally become more specific about faculty responsibility concerning creating inclusive environments, faculty need to understand and be supported in their efforts to transform the landscape of educator approaches in engineering education. Soon, faculty must, "…demonstrate knowledge of appropriate institutional policies on diversity, equity, and inclusion, and demonstrate awareness appropriate to providing an equitable and inclusive environment for its students that respects the institution's mission." [1, pg. 51]. This is likely due to the fact that while undergraduate graduation rates for women and historically marginalized students in engineering programs in the US have improved from 2008 to 2018, the total degrees awarded to students of color and women are still far below population representation [2]. Research has shown that students from underserved groups are more likely to persist when they see the link between their coursework and improving society. At the same time, human welfare components are becoming a part of accreditation protocols [3], [1]. These two factors, retention and accreditation compliance, create an opportunity for improvement in engineering education that has the potential to simultaneously address both. We believe the seeds of this improvement strategy may already be in use and examine through a linguistic and cultural lens the rhetorical strategies instructional faculty use to communicate technical concepts to students with the hope that we can increase utilization of these strategies to benefit students and simplify recommendations for instructional faculty who are striving to be compliant with ABET and other accreditation bodies and manage their workload within realistic constraints put on educational institutions.

Purpose: We believe that by explicitly articulating the applications of coursework to society, learning objectives to social service, and faculty commitment to advocacy for equitable practices in engineering education and practice we can lay a foundation for a learning space that effectively supports engagement and a sense of belonging among our students. There are a myriad of ways faculty approach engaging students in technical classrooms. We identify three teaching strategies that incorporate social impacts in technical courses. In this paper we identify and examine the characteristics of discourse and rhetorical strategies and how emphasizing inclusive and equitable delivery may impact student perception of technical courses and their position as learners.

Method: Instructional delivery in engineering education spaces is varied and deeply contextualized. Because we believe the specific terms and the tone used to introduce key disciplinary concepts creates a setting that can support student success and foster growth-mindsets over time, we conduct an inventory of language use practices of instructional faculty in order to understand how these practices, which are already being used by faculty, can be intentionally applied on a larger scale to better support all students and help faculty communicate their efforts to administrative and regulatory bodies. To enrich our understanding, we conducted field observations and interviewed instructors of courses in which these inclusive language practices are applied and result in the instantaneous integration of social impacts and technical coursework in engineering education. Social impacts in this context are defined as the environmental, economic, policy, socio-cultural, public welfare, and human/technology interaction areas that practicing engineers need to be aware of, and competent in, to create solutions that take into consideration structural conditions, reduce risks and minimize harm to underserved communities, and enhance human capability [4], [5]. We then analyzed these notes and instructor responses using a linguistic and cultural lens and framework of student success supported by awareness of diversity, equity, and inclusion.

Results: Preliminary results show that faculty are already incorporating social impacts into engineering education through discourse and rhetorical strategies used in lectures and course discussion through three fundamental methods: modeling the limitations of their own personal expertise, positioning humans as more important than technology, and application exploration/storytelling.

Conclusion: Through the use of examples, personal interactions, and application or classroom context-based anecdotes, faculty are already creating authentic microcosms of inclusive classrooms and are struggling to articulate how they do it to administrators and ABET. We suggest these resultant methods be used to create microinsertions of ethics and social impacts as one strategy for minimizing the technical/social dualism present in most curriculum [6], [7] which we hope will prove a rigorous strategy for the eventual full integration of sociotechnical approaches to problem solving in engineering education.

Introduction

There is a lack of consistency concerning integrating social impacts fully into technical lessons, modules, courses and ultimately engineering education programs. Social impacts in this case are defined as the environmental, economic, policy, socio-cultural, public welfare, and human/technology interaction areas that practicing engineers need to be aware of, and competent in, to create solutions that take into consideration structural conditions, reduce risks and minimize harm to underserved communities, and enhance human capability [4], [5]. Here, in order to identify and examine rhetorical strategies and discourse patterns created and utilized by faculty toward this effort, we review the literature and have found there are three main categories that have been used to incorporate social impacts in engineering education: full separation from, partial integration into, and full integration into technical courses.

Study topic

The result of the literature review is a general call for a change from fully separated and partially integrated social and technical coursework to fully integrating social impacts into engineering education both in discrete courses and programmatically. However, comprehensive and consistent understanding of how to fully integrate these topics is unclear.

We know that current efforts to enhance the focus and impact of diversity, equity, inclusion, belonging, and social justice (DEIB+SJ) supplemental support systems for students cannot combat the overarching effects of society and systemic systems of oppression on those students [8]. Going beyond DEIB+SJ as an isolated topic *additional to but not integrated into curriculum* is vital for the transformation of engineering education programs to ensure students have safe and inclusive learning spaces. Simply stating an institutional policy or populating a website with photos of diverse students collaborating is not enough. From an administrative and practical perspective, accreditation bodies are defining and starting to specifically require inclusive classrooms and faculty competence in these areas [1], [9]. Performance and evaluation of compliance with these new requirements is still largely undefined and this paper is an effort to identify discursive methods and rhetorical strategies that are *currently in use across university classrooms* that could be exemplar of productive and effective approaches for incorporating social impacts into technical courses.

Context

We have known for a while that the time spent training to become an engineer is an important and formative time for engineering students. Engineering education is the 'causal relationship' that links education to the development of technology and products for consumer use and company profit [16, pg. 149]. To ensure students feel safe enough to learn in their programs and truly engage in that formative process, engineering educators must communicate precisely and with care to address the lack of positive student engagement. We refer to these communication techniques as rhetorical practices. Building on Perrault [10, pg. 64] who states that, "...rhetorical knowledge is just as important as content knowledge," we refer to a practice as an intentional behavior with specific meaning within a community. In addition to easing the burden on educators trying to inspire the next generation of engineers, these strategies are based on best known practices to 1) retain students as populations across the United States decrease and change demographically, and 2) to graduate engineers ready to tackle incredibly complex social problems.

During this formative time in engineering education, the curriculum, interactions with faculty and peers, and course options give students insight into which skills are necessary and which are supposedly optional for practicing engineers. Berdanier [11] makes it clear the "optional" skills often are those most demanded by industry and necessary to solve the complex problems present in engineering practice. These skills are often ignored in engineering education, or siloed from required technical courses which creates an appearance of unimportance [9]. Despite these issues, the incorporation of social impacts into engineering education and clear, consistent strategies for doing so will aid in the effectiveness of engineering education and tighten that foundational connection between how engineering students are trained and the problems practicing engineers face in industry.

Significance

Momentum has been building in higher education to promote team building, context-based learning, and design thinking early in undergraduate curriculum in engineering programs to combat this status quo and to retain traditionally underserved populations of students [12]. Regulatory bodies are transforming student outcomes as emergent research continues to demonstrate this connection between technical and social topic areas and the need in industry for student proficiency in both.

Accreditation bodies are progressively requiring more effectiveness in the integration of social and technical solution spaces as programmatic outcomes for students. It's been over 15 years since ABET included, "the ability to: (1) function on multidisciplinary teams, (2) communicate effectively, and (3) understand professional and ethical responsibility" in their criteria [13, pg. 227]. Expectations for improving student abilities in these areas are only continuing to be more well defined and explicitly required [1].

Engineering education has historically left the ethical and humanitarian aspects of complex problems to courses in other fields [14]. In practice, engineering includes solving complex problems that span topics that cannot be perfectly delineated into purely technical or social. Practicing engineers make decisions that have a direct impact on society, communities, and human welfare [15]. If engineering education does not teach students to consider the weight of their decisions in the context of social impacts, then the field suffers the consequences of stagnant innovation, exclusionary practices, and withering participation [16], [17]. In this way it makes sense that the literature indicates a need for an approach that incorporates sociotechnical thinking in engineering education, and we believe the need will only increase as over time people become more connected with each other and technology.

Problem statement

The inclusion of social impacts and social justice concepts in technical courses creates context-based learning which has been shown to increase retention and interest in women-identifying students [12]. Engineering problem sets have historically been distilled into their most basic terms for the purpose of increasing practice problem throughput, the result of which is the complete stripping of the human element from problem solving skills in undergraduate curriculum [5]. **The ramifications of this are that engineering students go into engineering practice ready to tackle textbook problems without any weight or consideration given to the populations their solutions will impact.**

Literature review

The purpose of this literature review is to position our study as contributing *fundamentally sociotechnical* communication through discursive and rhetorical practices to improve engineering education. We follow the language people use to teach engineering courses with the hope that by making practices explicit we will establish both the pedagogical connection between strategic rhetorical practices promoting student success, and instructional approaches used to incorporate social impacts into engineering curricula that currently exist.

Right now, the literature indicates that the methods for incorporating social impacts in engineering education are categorized into 1) full separation from; 2) partial integration into; and 3) full integration into technical courses. Digging into the third and most recommended, yet least explored, option we found that *the way to fully integrate social impacts into engineering education is not yet clear or consistent across programs or research groups.*

Rhetorical practices as pedagogy

This study examines the value of discursive and rhetorical practices and strategies for engaging students in sociotechnical thinking. Two pedagogical endeavors are defined from this lens. First, specific rhetorical practices and modes of instructional delivery construct student perception of the importance of social impacts in their engineering programs through the perpetuation or dismantling of technical/social dualism and meritocratic ideology [7], [6]. This means there is an opportunity for finding ways that instructors can influence their classroom environments and sculpt their curriculum and delivery to create inclusive course environments and promote access and efficacy in engineering education. Second, essay writing and critical thinking tasks centered on understanding of the potential social impacts of engineering have been demonstrated as an effective means to engage students in sociotechnical thinking [9].

There is overlap between these two pedagogical applications of rhetorical practices and strategic discourse and the premise that sociotechnical thinking can develop more robust engineering education (and eventually practice) for all students. Research targeting the creation of inclusive cultures of belonging to increase student engagement in STEM fields supports the premise that instructors can position students as agents of their own learning and contributors to knowledge through course delivery and that these types of efforts spread throughout technical curriculum have an impact on student engagement and "[disrupt] the dominant technocentrism in engineering" [8], [18, pg. 492]. We present specific instances and examples of these types of *sociotechnical discourse* in engineering classrooms such that we hope to amplify the potential impact of these proposed methods in engineering education settings.

Impacts on underserved communities in engineering

Underserved students tend to have to work harder to meet the standards of engineering education classrooms because they constantly have to switch between their home knowledge and scholastic content as if there is no bridge or commonality between them [19]. Similar detrimental impacts have been documented for black and brown students in other classroom settings where they must "code switch" between the linguistic techniques used at home and those they are expected to perform for a grade [20]**.** When the separation of "rigorous" technical curriculum (here defined as decontextualized, distilled, and high throughput problem-solving) from the social impacts that create, surround, and inform them becomes apparent (likely not until students are in industry settings), it is too late to reverse the trend or supplement with extra training.

The landscape of engineering education must improve its cohesion with communities and consumers. If this is not addressed engineering in practice will continue to suffer a reputation of exclusivity and distrust as it decenters societal impacts from decision-making processes, since “[it] is in fact absurd to assume that disengagement with the world is a prerequisite to technically and morally robust decisions, products, and practices [21, pg. 13].

Through examination of structural trends of student belonging Campbell-Montalvo et al. found that when students were warned of the difficulty and the prejudices they will face, the students fared better due to lowered expectations and or increase preparedness [22]. This is one way to articulate authentically the complexity of real-world problem-solving settings that can be used in the classroom to enhance student experience. It has been shown beyond engineering fields that accommodations and universal design principles utilized for an underserved population benefit everyone [23]. It follows that **efforts addressing the evolving ABET requirements will create a more robust link between engineering education and practice and improve experiences for all students.** While this underpins our reasoning for looking at accommodations, universal design, and authentic articulation of the complexities of engineering practice, it should be noted we are aiming to identify strategies that improve conditions for engineering students while easing delivery strategies for educators. Our primary focus on student needs is based on Danowitz & Beddoes [24] groundbreaking study where they demonstrated empirically that engineering students struggle with mental health issues and have very specific challenges to overcome no matter what demographic populations they identify with.

Identification, evaluation, and exploration of the impact of discursive and rhetorical practices in instructional materials and classroom discussions that are customized to engineering education may have broader use in other majors or programs. Here we review the main categories that have been used to incorporate social impacts in engineering education: *full separation from, partial integration into, and full integration into technical courses*. We use this review to position our hypothesis about language as one form of fully integrating social impacts into engineering education.

Organization

This literature review will be presented in sequence from the most written about and researched topic of full separation of social impact from technological courses, move to the methods folks have used to partially integrate these topics, and finish with the latest empirical studies on full integration methods and results. We then unpack the implications of the literature review to set up the conceptual framework under which this study was completed, review the study design and methodology, and summarize the conclusions. This is done with the aim to understand how to forge a stronger connection between technical content and social impacts through the examination of prior efforts by different groups around the world. We acknowledge this work is often deeply contextualized and specific to certain classrooms, faculty, institutions, and environments and as such have explored a non-exhaustive but wide breadth of approaches in the literature and understand this is a first step in a larger process of creating a standard for creating spaces that foster sociotechnical approaches in engineering education.

Full separation of social impacts from technical courses

Technology is an inherently social activity, the neglect of which in engineering education influences the ability of practicing engineers to critically analyze and ethically judge the long-term impacts of their designs [25]. Legacy pedagogical methods that persist today in engineering education are those of the siloed ethics course that focuses on Codes of Ethics from different disciplines and case studies of specific, emergent, and well-defined ethical dilemmas students cipher through to find the one and only *right* answer. The result of this approach is the disconnection between ethics and engineering design and practice [14], neither of which are well-defined and both of which utilize tradeoffs and agile decision-making rather than finding perfect solutions. A longitudinal study of 266 undergraduate engineering students found that participation in siloed ethics courses in their programs had minimal impact on student understanding of ethical issues in engineering practice. The authors conclude, "most types of experiences (e.g. taking a single ethics course, participating in a service-learning experience) are probably not substantial enough to have measurable, long-term impacts on most students" [26, pg. 10]. The compounding effect of this separation of social impacts from technical classes creates a 'culture of disengagement' when combined with legacy pedagogical strategies such as prioritizing decontextualized, distilled, and high throughput problem-solving over critical thinking and context-based learning [7], [5].

Contrasting this isolation of "the engineer" from society with the reality that in industry, engineers can only succeed in advocating for social impacts and implications concerning their projects with corporate, legal, or colleague support [27]. It has been established that engineering education is direct preparation for engineering practice, therefore education must help students develop strategies for advocacy and navigating complex systems, solving complex problems, and collaborating across disciplines. These social interactions which result in the creation of supportive networks in industry are necessary to be a successful professional engineer. Methods and mechanisms for doing this may be modeled through the discourse with instructional faculty, course materials, and class discussions [28].

Implications from full separation of social impacts into technical courses

A key hypothesis of this study is that if faculty teaching engineering can effectively model social justice advocacy and awareness in both the form and content of their courses, then all students, including those from historically marginalized groups, would benefit from increased engagement, success, and retention. Within the context of teaching the question remains how to facilitate and create those interactions. In form, educators must intentionally demonstrate both inclusive communicative terms, tone, consideration needed to promote socially-just work cultures, and the problem-solving and solution-finding sociotechnical perspective. In content, there is a large disconnect between typical assessment methods associated with social impact assignments compared to their technical counterparts [6]. This is how even in one course that aims to combine social impacts and technical concepts the lingering effects of full separation can occur.

Partial integration of social impacts into technical courses

There are folks working on methods for and determining the efficacy of incorporating social impacts in technical classrooms beyond a single or siloed course within the overall curriculum. This is driven by the knowledge that minimizing unconscious bias and deficit-based approaches can create better environments for all students and bring long-term benefit to the engineering community [29]. In addition to explicitly stating context when teaching content to students, an approach using high and low context language styles has been shown to foster metacognition of the tasks assigned to students learning technical content simultaneously with the surrounding social details [29]. Students under this multicontext condition can then position themselves in relation to the task, its place in society, and may be encouraged to take innovative risks traditionally devalued in engineering education. By doing so the outcome is minimizing one of the main drivers of the, "disconnect between the objectivity of engineering courses and the subjectivity of engineering practice…" [9, pg. 689].

Barriers that mirror those described above in the full separation of social impacts from technical coursework exist in the programs where partial integration has been evaluated. In interviews with 26 undergraduate, graduate, and PhD students and 60 ethnographic observations of engineering program events, classes, presentation, and social groups Niles et al. [18] found that integrating social impacts in technical coursework, "...disrupts the dominant technocentrism in engineering and unsettles boundaries of engineering identity, practice, knowledge, and ethics—creating challenges for students to engage with public welfare concerns" [18, pg. 492]. These authors note that even the most cutting-edge programs they reviewed are still designing curriculum such that the separation between social impacts (in their case defined as public welfare) and technical content is bounded across courses or between modules within courses. The positivism created and perpetuated by this silo in engineering education ultimately positions *rightness* as a hidden, structural, exclusionary force rather than something **constructed** by the people in the room. The authors conclude that students are working at a boundary condition created over years of separation between the physical and social sciences and this itself is another barrier. Students struggle with their engineering identity when centering public welfare or justifying nontechnical work after experiencing partial integration of social impacts in technical courses, and "[this] kind of negotiation [reflects] the tensions and unsettled boundaries between what students [consider] to be inside or outside the scope of their responsibilities and practices as engineers" [18, pg. 498]. Ultimately, they recommend full integration over partial integration.

Chang et al. worked to use social inclusion in the design stage of curriculum development to bolster professional development and, "increase socially responsive value in the professional development of student engineers" [3, pg. 237]. They use "social informatics" which they describe as a "meta-discipline" that explores ethical and social impacts into structural and interactional patterns between people and technology. The curriculum was designed for engineering seniors and graduate students as a single service-learning course. It included working on technical projects and directly with the users to determine how well the products fit customer needs. Ultimately, they found students, "...through action research, not technology per se, became increasingly self-motivated and committed" to their projects [3, pg. 244].

Implications from partial integration of social impacts into technical courses

A key assumption of this study is that faculty are *already making decisions and creating emergent techniques that incorporate sociotechnical thinking in their classrooms,* but are doing so in small, discrete, often overlooked or undervalued ways. Each partial integration study reviewed here used different methods for incorporation of social impacts in engineering education with mixed results and each identified specific and unique barriers to progression toward full integration. The main takeaway here is that full integration of social impacts into one technical course is still programmatically partial integration and therefore has the same repercussions of siloed courses within the curriculum such as the continued perpetuation of the technical/social dualism present in engineering education.

Full integration of social impacts into technical courses

Recent efforts to determine what full integration of social impacts in engineering education looks like are complex and specific to the courses taught and programs they populate. Leydens, Johnson, & Moskal [30] use the Engineering for Justice framework [5] to fully integrate social justice (and therefore many social impacts as we define them) into technical coursework and gauge student reception. Their empirical case study shows mixed results. Leydens, Johnson, and Moskal refer to <u>Engineering Justice</u> [5] and Riley's landmark work <u>Engineering and social justice</u> [4] to explain that, "While the theory behind engineering and social justice in education has been explored, relatively few publications exist on the actual integration of social justice in the curriculum or student perspectives on such integration" [30, pg. 721]. Their study consisted of a 3-year qualitative case study where students who participated in both legacy (full or partial separation) and novel (full integration) curriculums were interviewed individually and in focus groups. The curricular implementation of sociotechnical content in engineering education was as follows:

1. Present social context when introducing an engineering problem
2. Accentuate and make transparent structural conditions
3. Acknowledge human agency given various sociotechnical constraints.

The authors propose that sociotechnical content in general *already exists and just isn't discussed* in legacy curriculum. Their framework and methodology explore student reception to the integration of those existing aspects of sociotechnical thinking in traditionally technical classrooms. They find that some students are inspired and intrigued by the complexities of sociotechnical problem solving while others struggle to move past a more strict, isolated definition of engineering. In the final analysis the authors recommend full programmatic integration as vital to addressing the differences in student reception of sociotechnical problem solving.

Cote and Branzan Albu [9] performed a case study of full integration of socio-cultural impacts which they define as student-identified topics related to technical projects in a capstone course for computer vision technology. The definition of socio-cultural in this context includes but is not limited to the environment, ethics, social relations, personal development, economics, health/medicine, law, elderly, and politics [9, pg. 697]. The authors describe how both the Canadian accreditation body (CEAB) and the European Network for Accreditation of Engineering Education (ENAEE, which serves Germany, France, UK, Ireland, Portugal, Russia, Turkey, Romania, Italy, Poland, Switzerland, Spain, and Finland) incorporate social impacts and awareness of social implications in engineering design in their student outcomes. In other words, ABET in the United States is aligned with international movement. The authors identify that CEAB compliance typically includes a single standalone course on society and engineering impacts (full separation) rather than integration of the socio-cultural with the technical coursework. They articulate the ramifications of this, and the need for their study, as the following:

1. Students as early as the first year devalue courses that have social impact components as lesser than their technical courses, and
2. The course being differentiated lends to the student perception that while interesting it is less important.

The method used to create a partially integrated sociotechnical learning environment was assigning an essay as part of a technical project course so that students were required to explore the socio-cultural aspects of the technical content.

Bissett-Johnson and Radcliffe [31] completed a cross sectional case study of a single project-based course over ten years. They took the metrics for success and viewed the results from a socio-cultural, techno-sphere, economic, and environmental lens to determine how well students were understanding the context of their projects from the three perspectives: 1) Socially Responsible Design, 2) Appropriate Technology, and 3) Human-Centered Design which were formed into a pedagogical model. They found that over the time period of their study, as the socio-cultural context was increased, the technical outcomes did not suffer (i.e., there was no detriment to technical skill in the students or project outcomes when the focus was also on society and human life) [31].

Implications from the literature review

Based on the literature reviewed, both *full separation of social impacts from technical courses* and *partial integration of social impacts into technical courses* fall short of achieving the desired outcomes by reifying existing norms devaluing and decentering social considerations as "non-technical." Adding social impacts and considerations as addenda or modifying some parts of a course serves to more clearly illuminate the overwhelming emphasis on and value of decontextualized technical problem-solving, leaving both students and educators more aware of the problem, but without meaningful solutions or next steps.

So full programmatic integration is likely required to achieve the educational outcomes desired from sociotechnical problem solving. This aligns with our theoretical framing because engineering programs were designed and built intentionally to separate the social from the technical, and small changes to those designs wouldn't be expected to alter their outcomes. However, our review of the literature reporting *full integration of social impacts in technical courses* notes three distinct approaches: 1) a combination of presenting social contexts, making structural conditions transparent, and acknowledging human agency [30], 2) an integrated and robust written component of the course exploring the social impacts of technical projects in capstone courses [9], and 3) thorough contextualization of technical projects [31].

Full integration of social and technical problem solving, then, requires educating students and faculty about *how* to integrate social and technical issues in their classrooms. The integration is not only a change in structure, but a learning objective: students must be shown and immersed in examples of sociotechnical thinking. Additionally, sociotechnical thinking is complex, relatively new to many engineering educators, and based on pluralistic social sciences where multiple valid understandings are assumed and valued. How do faculty and students develop and share these new ways of thinking, assuming they are supported by structures and curriculum in a full integration model? The potential knowledge-gain for programmatic improvement in this area is vast.

The varying degrees of implementation across the full integration category situates our inquiry as one that explores ***how*** social impacts are incorporated into technical courses and curriculum. Leydens, Johnson, & Moskal, [30] point out that social impacts *already exist* in technology-driven spaces and by being left out are negatively impacting student readiness upon graduation for industry. In this paper, we advance this idea by offering that there are viable, unidentified, and undervalued discursive and rhetorical practices that may strategically, through microinsertion across courses and programs, create a body of knowledge around sociotechnical pedagogies that does not yet exist that may be utilized by faculty who desire to be in compliance with accreditation bodies and make their classrooms more inclusive.

Conceptual framework

Constructivist learning theory

For the last century or more within the field of educational program development, approaches to andragogy, or adult learning theory [32], have shifted away from models where educators *"deposit" knowledge into the waiting minds of students* (which the authors of this study wish to continue to disrupt) and toward constructivist understandings of the learning process [33], [34]. This constructivist understanding emphasizes the culturally-specific and relationship-centered way that knowledge is created and shared between individuals in communities of learning [35].

Cultural studies and language theory at play in engineering education

The concept of knowledge as a construct that has political implications for individuals and society also coincides with the foundational concepts from the fields of rhetorical and cultural studies that prioritize examination of language and language usage practices as powerful influencers of the way people understand the world and decide to act within it [36], [37], [38], [39]. As such, **the rhetorical practices that educators use to create a context for instructional delivery have large implications for students' learning,** including and especially in engineering education. And, if engineering education is to be successful at providing opportunities for students to achieve learning outcomes that align with social consciousness and critically consider social impacts, it is imperative for engineering educators to intentionally apply rhetorical, discursive, and linguistic practices that support an awareness of social impacts and social justice concerns.

Application of conceptual frameworks to this study

To address all of these intersecting developmental needs and answer the primary research question: *How do faculty integrate social impacts into engineering education?* the present study applies the overlapping concepts from multicontext and constructivist learning theories as well as critical rhetorical theory to understand and analyze the linguistic practices used as a medium for engineering education that focuses on incorporating social impacts. Then, in order to explore the implications of those practices, we adopt Crick's [40] "deep engagement" model on which to ground findings for impacts of these practices on student success factors. Specifically, this model (see Fig. 1) suggests that learners must encounter global, social, and personal contexts for learning, including through relationships with others and communities of learning that have meaning that reaches to the core of identity in order to authentically or "deeply" engage in learning.

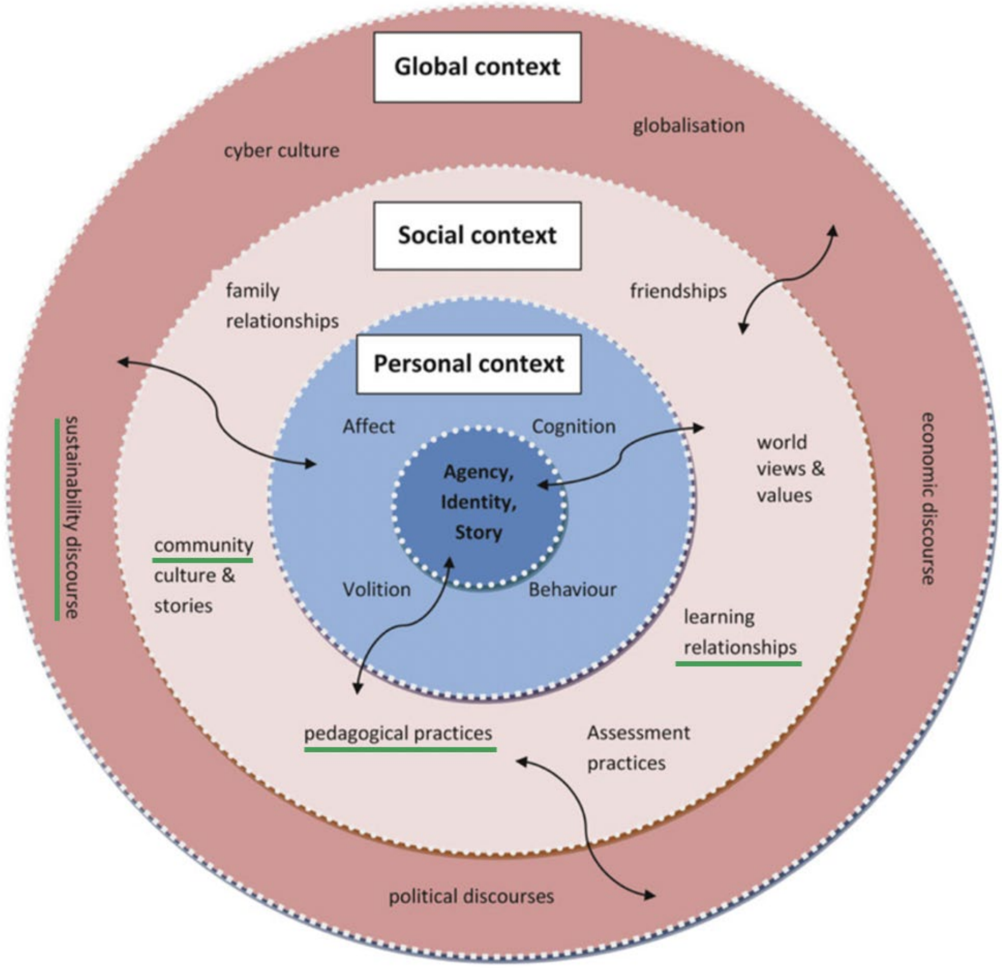

Fig. 1 Crick's [40] Model of "Deep Engagement" shows the layered contexts through which engagement occurs as a process of relationship, community, agency, identity, and storytelling.

We know that faculty feedback has a direct impact on student engagement and what students consider imperative to learn [41]. As such we assert that there is an opportunity for discovery in observing and evaluating ways in which instructional faculty teach content and establish or co-create their explanations in class to effectively communicate technical content to students such that social justice concepts reinforce engineering principles and lessons.

In legacy pedagogical methods the development of knowledge is “passed” (rather than created) from the technical “expert” and then “constructed” or reconstructed by students during their interpretation and practice. Since the purpose of this study is to explore and gain an in-depth description to understand as much as possible about how faculty teaching technical content include social impacts and social justice perspectives into their courses a well-bounded and collective case study approach was chosen [42].

Study Design and Methodology

RQ: How do engineering faculty incorporate social impacts into their technical courses?

Setting and recruitment

Many faculty members teach engineering science courses each with their own unique perspectives and curricula. It was essential for this project that faculty were selected who had a foundational understanding of sociotechnical integration as outlined in this paper. It was also important that we identify a common course to observe that prioritized these concepts in some measurable way. Over time this type of exploration into sociotechnical integration is becoming more accessible as accreditation requirements become embedded into course learning outcomes and student learning outcomes.

For this study we focused on a first-year engineering program at a west coast university which includes articulating social impacts as a student outcome. Three faculty members were selected for this collective case study that utilized observation and in-depth interviews with participants to understand multiple perspectives to provide validity and triangulation [43]. Each faculty member’s approach was observed during lecture and follow up interviews were conducted. Participants’ expertise is not identified to protect the anonymity of faculty but allowed for data collection of methods across diverse engineering backgrounds.

Positionality

This project used a constructivist approach because working to incorporate diversity, equity, inclusion, and belonging in engineering is built within contexts where multiple parties and motivations exist simultaneously, and solutions must emerge collaboratively. When I (Ingrid) finished my engineering degree I was abhorred by how little I knew concerning opportunities within my field and what was expected of me in industry. In industry, I had to find my own meaning while trying to complete complex tasks assigned to me by managers, technical colleagues, and customers. Engineering practice for me became as much about interaction with those individuals and collaborators as the technology itself. Leydens and Lucena present a framework in their book Engineering Justice [5] that establishes methods for integrating criteria in courses such that the human factors rampant in engineering practice are present in engineering education. This was the missing link for me when I was a student preparing to apply for internships, jobs, and try to formulate an idea in my mind concerning how a career in engineering might materialize and be fulfilling.

Research approach and rationale

The focus of the field observations in this study was the creation of knowledge through the mutual understanding of the instructional faculty and students within the constructivist view. From a researcher perspective specifically, I was looking for any emergent indicators of social impacts *integral* to the understanding of technical concepts in classrooms. This work is unique because we come from an asset-lens perspective when viewing hard working faculty who are navigating new accreditation expectations and increasingly diverse student populations.

The ontology associated with constructivism is relativism such that constructed realities are context-based and specific to the location, participants, researchers, and settings. The epistemology of constructivism is transactional meaning between people or groups, and the methodology is related to dialogue and discussion of topics and ideas [44]. This fits with our conceptual framework and deeply-contextualized exploration into the incorporation and integration of sociotechnical problem solving in engineering education.

Since the research question in this collective case study is: **How do engineering faculty incorporate social justice into their technical courses?** We explore phrases, concepts, activities, and look for emergent discursive and rhetorical practices as outlined in the introduction, literature review, and conceptual framework. Each of the three participants that taught a course with at least one course learning outcome emphasizing social impacts had some methodology or method concerning how to integrate social justice into their technical content, some more carefully constructed than others. Observations focused on the way instructional faculty scaffolded technical concepts through human usability lessons, application exploration, or reminders to students in real-time through metaphor or storytelling of their worldly experiences and how the technical content applies to them and the limits of their expertise. Each unique approach was explored in in-depth interviews after field observations were complete to understand the mechanisms through which these techniques emerged.

Results

There are three main ways the participants in this study incorporated social impacts into their technical classes. Faculty: 1) modeled the limits of their personal expertise, 2) positioned humans as more important than technology, and 3) explored applications or told stories to expand course topics. Each of these three techniques are used in the construction of sociotechnical knowledge and problem solving in engineering courses. Detailed explanations and examples of each technique are described in the following sections.

Modeling the limits of expertise

Legacy engineering education pedagogical techniques often include expert lectures and assessment based on how well the students can, under exam pressures, recollect and regurgitate information in the same format, with the same standards of accuracy, and to the same extent (or more) as presented in lecture. These behaviors perpetuate an echo chamber effect where new ideas are discouraged and the personnel who hold expertise continue to glean unlimited clout for repetitive work [45]. Since we know the positioning of students as agents in their own learning contributes to a sense of belonging in classrooms [8] it follows that a depositioning of the lecturer as the essential and only authority allows room for students to experiment with their own agency and authority in the classroom setting.

Each participant modeled the limits of expertise in some concrete way in class and in the subsequent in-depth interviews. In the interview, Participant1 stated, "...I also…want myself to be a person…for [the students] to see me, not just as this, like, stiff engineering writing equations on the board." This topic was also mirrored in lecture when Participant1 answered a student question saying, "I don't know the answer…it could have to do with density" modeling an inexpertise on a topic related to the technical content being delivered. This uncertainty from the faculty member left a palpable feeling of space in the room for other considerations since a definitive, certain, and singular solution was not presented. This same participant later stated in class, "I admit I didn't understand this as an engineer until about ten years ago but it's basically a hydraulic pump" further emphasizing that learning engineering *takes time and context* and those who have been in the field for years continue to improve and gain deeper understanding.

Participant2 explicitly stated in lecture that there will always be room for improvement and progressive technical understanding, "As soon as you have figured out Excel, they'll [the developers] change something. Know it's something you are always learning." This sentence does two things that support modeling the limits of expertise from the faculty member. First, it names "they" — the engineers who developed the software the lesson is focused on — as people and asserts that "they" will always be improving. Second, it treats technology as something fluid and evolving rather than a static "one size fits all" answer that doesn't exist in a temporal context. In the interview this participant dove deeper into the topic of continuous improvement and their goal for their students:

> I just, you know, my goal is to never shame. So, and just [to] sort of create the environment that you know we're here to learn…we're trying things out…we get things wrong and invariably because I am the person, I am, I get things wrong in front of the class, too, sometimes. So, I say, see, we're all human. We make mistakes. It's okay…we're here to learn…We're always getting better.

Finally, Participant3 went beyond modeling an individual limit of personal expertise and reflected on their own educational experience, saying, "I wonder if it's one of those things they taught me that then fell out of fashion." Participant3 was talking about a method for calculating a physical parameter within an accuracy metric. They attempted to do an example in the classroom, got an audible error message from the computer, and said, "Boo you shut up" *to the computer as if it was not smart at all but rather something that should function for the user*. While the direct quote about educational content as having obsolescence is an example of modeling the limits of expertise, this secondary "talking down" to the computer is a great segway to the second emergent technique using rhetoric for incorporating social justice and impacts into technical content: the positioning of humans as more important than technology.

Positioning humans as more important than technology

It is important to remember that humans are what drive technology and while technology is necessary for human survival the design of that survival should include many voices, especially those historically marginalized [17]. Studies have shown that marginalized groups are more likely to stay in careers with a clear potential social impact and contribution [5]. This connection also appears in research in student engagement in STEM fields [12]. To effectively incorporate these content considerations into engineering courses, they must be explicitly stated in course learning outcomes that include recognition of social or structural inequities such as: racial, cultural, gender, socioeconomic and accessibility as essential to engineering. The values inherent in these considerations must also be evident within the framing of tasks presented to students. Positioning humans as more important than technology was one way participants in this study showed the structural and social impacts of technology and changed the way it's traditionally presented in engineering education.

Participant3 was the most vocal about positioning humans above technology. The lesson was focused on learning to use Excel and the constant back and forth between the faculty member's instructional dialogue and asides about their personal frustrations working with the software were effective in centering the students as valid in their trepidations concerning its use. Participant3 constantly went back to what the problem is, what humans know about the problem, and referred to computers as mere tools to get the more boring parts of solving complex problems done. In the interview they explained why they do this in class:

> And that's really, really valuable [to me]. And an important…distinction that a computer can't [understand anything]. They can give you a lot of pictures to make stories about, but the actual meaning has always to come from a person.

In class, to make the above point clear to those learning software tools, Participant3 further positioned the students as *people with agency and advantages over technology* saying, "When we try to break it down into steps a dumb machine can do…we break down something we do intuitively into something a computer can do."

Application exploration and or storytelling

Since each faculty member had a different background in engineering it was interesting to observe the ways their analogies, anecdotes, application areas, and stories informed the students about a particular technical topic. Participant1 when discussing calculating energy balances told their students, "We will calculate it like a bank account" calling up a likely standard student experience of balancing income and expenses to talk about transferring energy between physical entities. When the discussion turned to what mechanism allowed for this transfer and how different physical phenomena accomplish it, the faculty member stated in response to a student prompt, "[Yes] essentially that's what evapotranspiration is is plants sweating" not only acknowledging the student's contribution to the class but specifying how well the personification fit the lesson for the rest of the students and giving that student credit for their idea.

Participant3 when reviewing the accuracy of their Excel outputs explicitly asked students, "Does everyone have a story in their head for why this efficiency looks so wrong?" Simultaneously centering storytelling as a valid approach to problem solving and reinforcing the aforementioned positioning of humans and their intuitive ability to solve problems above computers as number crunching machines. Participant3 went deeper during the interview to explain, through storytelling, how they perceive the educational system and their role in facilitating student learning:

> My understanding of humanity and social systems leads me to think…it's like hydrology to me. There's a landscape, and we're all raindrops. And so there's these streams, and it's not like this stream chose to be this shape. It's like, well, there's a big rock formation here, and then the thing there kind of just happens to do that because of the system in place. So we have the system and our students are moving through it.

These themes emerged independent of prompting from the research team as central to the faculty teaching methods and intentions. There seem to be correlations between the ideal methods for sociotechnical problem solving and fostering metacognition. Metacognition in student learning has been shown to take extra time but result in extra benefit around a topic area (Perrault, 2011) and may be another way to approach this process of discovery in the future or to assess the efficacy of sociotechnical content delivery in engineering education courses and or programs.

Conclusion

Limitations

There is a perceived tradeoff, acknowledged directly or peripherally by all participants in this study, that incorporating impacts and maintaining technical density in the course are combative forces. While that is outside the scope of this study where we aimed to and successfully identified discursive and rhetorical practices for incorporating sociotechnical content in engineering education it would be interesting to follow up in future work in this area. There is some empirical evidence that technical rigor does not suffer when combined with social impact curriculum [31] but getting more evidence in other contexts of this may help faculty feel more comfortable pursuing these techniques and strategies at all levels of undergraduate engineering education.

Working as a teacher in an engineering department this is also something I hear constantly — the battle between technical rigor and application areas or social impacts is a vast gap which *takes time* to bridge. The goal of this study is to find ways faculty are already incorporating social impacts in their engineering courses with the hope that these techniques may be scaffolded to upper division or graduate level courses. It is imperative to remember that *these concepts and contexts are already implicit in the design decisions made by engineers* and that if they are not acknowledged and incorporated into curriculum the consequences outlined in the literature review of this paper will continue to permeate engineering education.

There was a gradient among participants where some tried to balance the tradeoff by incorporating both technical and social content in the same class, over the same term, but not necessarily together. This is reminiscent of the partial integration of social impacts into technical classrooms section from our literature review. The distinction between technical content and social impact areas was more arduous to find in other instances as they were linked not only in time but also linguistically. This combination seemed to be the most effective but more work and a metric for student reception must be included in future work to verify this supposition.

Future work

Since only three faculty members were approached for this collective case study, the ways in which they incorporated social impacts in technical courses was an act of discovery and in no way exhaustive or comprehensive. Future work is recommended with more faculty involvement and more field observations to strive toward a comprehensive list of techniques employed to incorporate sociotechnical problem solving in engineering education. The valuable feedback from students after course observation will also be needed as these techniques are further utilized and explored. We believe that strategies for the incorporation of social impact areas in engineering education are deeply contextualized to the subject matter, instructional faculty, students, setting, and likely to the institution. Therefore a more focused major-specific or upper division course exploration might be of interest especially in a cross-sectional or longitudinal study for the purpose of further identifying and categorizing emergent techniques for the integration of sociotechnical content in engineering education.

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