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Using an open-ended socio-technical design challenge for entrepreneurship education in a first-year engineering course

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Engineering graduates must be prepared with sound technical knowledge and a range of 21st century competencies and professional skills such as creativity, interdisciplinary collaboration, communication, and innovation to successfully solve today's complex, global problems. Equally important is a deep appreciation of the degree to which technological solutions are situated within the context of human and natural environments. Despite calls from the National Academy of Engineering and several professional organizations to broaden engineering education to embrace these skills, most engineering programs persistently focus on the importance of technical skills. This paper describes an open-ended team-based design challenge that integrates entrepreneurial-minded (EM) skill development into an interdisciplinary first-year engineering course that approaches engineering from a socio-technical perspective. The challenge was implemented in two simultaneous first-year classes (n=49), with the goal of fostering students' broad professional skills and their appreciation of the links between engineering technologies and societal context. The action research study used a quasi-experimental design with convenience sampling and no control group to explore students' self-perceived entrepreneurial-minded (EM) skills development. Data were collected with a retrospective questionnaire comprised of a series of 5-point Likert-type questions that asked students to assess the development of their EM skills in all three areas of the EM framework: Exhibit Curiosity, Establish Connections, and Create Value (the "3C" framework). Results indicate that students felt they developed EM skills in all three areas of the 3C Framework, with more fully developed skills in the Establish Connections and Create Value categories. Overall, this study suggests the effectiveness of using open-ended, socio-technical engineering design challenges for developing skills that will better prepare students to work collaboratively on complex and interdisciplinary problems they will face in their professional careers.

KEYWORDS

design thinking, entrepreneurial minded learning, pedagogical innovation, open-ended problem solving, first-year engineering, socio-technical, interdisciplinary-academia

1. Introduction

In today's rapidly evolving economy, engineering graduates are expected to possess both technical competencies and professional skills to increase their employability in the industry (Cruz et al., 2020). Accreditation boards worldwide require integrating professional skills such as systems thinking, communication, collaboration, problem-solving, and critical thinking into engineering curricula to meet the needs of the labor market. The Accreditation Board for Engineering and Technology (ABET) provides a framework that requires students to develop broad professional skills by considering many different constraints and design applications that extend beyond technical content knowledge (ABET, 2021). According to Cohen et al. (2014), ABET—together with other engineering leaders such as the National Academy of Engineering and the American Society of Civil Engineers—have emphasized the need for future engineers to understand their work as existing within the social, environmental, and economic context of the present and the future. Framing engineering within a broader societal context can also improve retention of students who identify as female and from other underrepresented minority groups, who have been shown to be more sensitive to the connection between engineering and improving people's lives (Gaunkar et al., 2020; Roberts and Lord, 2020). Socio-technical thinking and socio-technical competencies are widely acknowledged worldwide across the engineering education community (Christensen and Ernø-Kjølhede, 2012). Studies exploring the benefits of integrating socio-technical competencies into engineering curricula suggest that engineers need to be purposeful and thoughtful in creating solutions for real-world problems (Sheppard et al., 2009; Mazzurco and Daniel, 2020).

However, while most engineering graduates are well-prepared with technical knowledge, they are not adequately equipped with broad 21st century competencies and professional skills to face complex, real-world challenges. Winberg et al. (2020) highlighted concerns over the job readiness of engineering graduates and found 'interactive skills' to be one of the core graduate skills that remain underdeveloped. Furthermore, Sumanasiri et al. (2015) raised concerns over graduate employability stating that despite having practices within universities to increase employability, it still remains problematic and lacks adequate clarity. Various other studies have emphasized the need to equip graduating students with professional skills to tackle real-world challenges (Nilsson, 2010; Nisha and Rajasekaran, 2018; Succi and Canovi, 2020).

This study attempts to bridge this gap by integrating socio-technical thinking and the entrepreneurial mindset into a first-year engineering course. The entrepreneurial mindset (EM) encompasses attributes of creativity, innovation, and opportunities that lead to organizational wealth creation and success, allowing people to make realistic decisions when faced with uncertainties (Neneh, 2012). Ireland et al. (2003, p. 968) describe the entrepreneurial mindset as a "way of thinking" that creates a competitive advantage from the positive aspects of uncertainty and creates complex and equivocal situations through cognitive abilities. Mitchell (2007, p. 13) emphasizes that "the entrepreneurial experience and mindset is an invaluable guide to a young industrial researcher" to legitimize the best management practices necessary for capitalizing on technological opportunities. Combining socio-technical thinking and the entrepreneurial mindset into the engineering curriculum can provide engineering graduates with opportunities to gain sound technical knowledge and develop the mindset to explore and exploit critical, complex societal issues and create innovative solutions that address these challenges on a broader scale. This paper describes an open-ended design challenge that integrates EM skill development into an interdisciplinary first-year engineering course that approaches engineering from a socio-technical perspective. This learning innovation provides a welcoming learning environment that enables students to develop skills to better prepare them to face complex challenges in a changing profession.

2. Pedagogical frameworks

The pedagogical innovation developed and assessed in this work is grounded at the intersection of two conceptual frameworks: entrepreneurial mindset (EM)/entrepreneurial-minded learning (EML) and socio-technical engineering design. Each is described below.

2.1. Socio-technical engineering design

According to Herrmann (2003, p. 60), a socio-technical system is a "combination of organizational, technical, educational and cultural structures and interactions." Socio-technical engineering design contextualizes the technical aspects of engineering work within a sociocultural and economic framework. Several efforts have been made to better prepare engineering students with an understanding of the needs of society (Freuler et al., 2001; Baxter and Sommerville, 2011; Chesler et al., 2013; Neumeyer et al., 2013) and, more broadly, to teach engineering as a socio-technical process with attributes of both technical (e.g., design, ideation, calculation, testing, etc.) and non-technical (e.g., problem identification, communication, creativity, empathy, etc.) elements. For example, Roberts and Lord (2020) developed a curriculum that infuses social and technical elements, including social justice, humanitarian practice, and peace, into engineering education. Cohen et al. (2014) introduced engineering as a socio-technical process to first-year college students by showcasing the merging of two disciplines, such as liberal arts and engineering. The course content developed for the study included the design thinking process primarily used in several entrepreneurship studies to cultivate professional skills in students.

The socio-technical design process involves exploring issues, exploiting available tools and knowledge, and using them to tackle real-world, complex challenges and develop novel solutions that meet market demands (Griffith and Dougherty, 2001). Indeed, there is a significant overlap between socio-technical design and the entrepreneurial mindset (Huerta et al., 2017). Incorporating both elements in a first-year course creates awareness of complex, real-world problems. It gives students early exposure to the importance of developing user-centered engineering solutions, focusing on diverse societal needs and considering deeply the context within which their solutions will be implemented (Kilgore et al., 2007; Bertoni, 2018; Choi-Fitzpatrick and Hoople, 2019).

2.2. Entrepreneurial mindset and entrepreneurially minded learning

Definitions of entrepreneurial mindset in the literature stem from combining the meanings of the words 'entrepreneur' and 'mindset.'

Mindset, which refers to decision-making and how people think, has been an area of interest in the cognitive sciences (Shepherd and Patzelt, 2018). The Kern Family Foundation (2022) describes the entrepreneurial mindset (EM) as a culmination of mental habits that empower people to question, adapt, and drive change in their communities, societies, and, ultimately, the world around them. The foundation's Kern Entrepreneurial Engineering Network (KEEN) has created a framework that identifies three essential qualities of entrepreneurial-minded individuals, referred to as the 3C's:

- Exhibit Curiosity: a continuous curiosity about making an impact globally and employing a contrarian attitude towards accepted notions;
- Establish Connections: a habit of connecting information from many sources to gain insights, stumble upon unexpected opportunities, manage risk; and
- Create Value: the ability to create value for others from unexpected ventures, showing persistence, and learning from failure and success.

Characterized by collaboration and leadership involving technical skills and curiosity, an ability to connect pieces of knowledge to discover solutions, and a focus on value creation (Bosman, 2019), the entrepreneurial mindset has received recognition for its importance in training engineers and developing an economy through innovation (Byers et al., 2013; Bosman, 2019).

Entrepreneurial-minded learning (EML) is defined as "a pedagogical approach emphasizing discovery, opportunity identification, and value creation while building on other active pedagogies such as problem-based learning" (Wheadon and Duval-Couetil, 2016). Entrepreneurship education has undergone significant and widespread change over the past 20 years. Entrepreneurship courses and elements of the entrepreneurial mindset are increasingly common in nonbusiness disciplines such as engineering, sciences, and the arts (Turner and Gianiodis, 2018). In engineering especially, the merging of entrepreneurship and innovation with the traditional engineering curriculum has become a prominent area of research (Eisenstein, 2010). Gilmartin et al. (2016) note that there is a diverse set of EM learning objectives to accommodate an equally diverse range of programs, from those geared towards entrepreneurship in the business start-up sense to programs focused on the entrepreneurial mindset.

EML is associated with other evidence-based, student-centered teaching and learning strategies such as design-based, collaborative, and project-or problem-based learning, strategies widely known to improve student engagement and learning (Felder et al., 2000; Hsieh and Knight, 2008; National Research Council, 2011, 2015; Bekki et al., 2018), develop professional competencies (Lamb et al., 2010), and to engage and retain a broader range of students (Knight et al., 2003; Fortenberry et al., 2007; Johnson, 2007). Studies have shown that EM learning activities increase students' awareness of entrepreneurially minded learning concepts and EM skill development (professional and technical skills) and have observed higher levels of motivation and self-efficacy (Souitaris et al., 2007; Boutell and Fisher, 2017; Henslee et al., 2021). Hadgraft and Kolmos (2020) propose distinct approaches to integrating EML and socio-technical engineering into complex projects to develop students' technical competencies and professional skills. Based on their recommendations for student-centered and contextualized learning that incorporates professional competencies, our 'open-ended socio-technical design challenge' was developed.

3. Research design

Our action research study explored the development of entrepreneurial minded skills among a group of students who participated in a team-based, open-ended socio-technical design challenge. We used convenience sampling and retrospective (post-only) data collection. Convenience sampling is commonly used in action research, as the instructor's students most often form the conveniently available pool of respondents who participate in the intervention (Mills and Gay, 2019). Our data collection approach was an adaptation of the 'posttest-then-retrospective-pretest' (Howard et al., 1979), whereby the pre-test is administered concurrently with the posttest by asking individuals to recall their knowledge, attitudes, or behaviors prior to the program (Allen and Nimon, 2007). In addition to convenience and versatility, this approach reduces response shift bias and has been shown to be a valid, efficient method for outcomes assessment (Klatt and Taylor-Powell, 2005a,b; Marshall et al., 2007). While this approach typically asks participants to self-assess what they know from two viewpoints—first 'before' and then 'after'—we used a single question to ask how they felt their participation in the project improved certain skills. In this section we describe the pedagogical format and relevant learning objectives of the design challenge itself, followed by details about the participants and the assessment plan.

3.1. Open-ended design challenge

The open-ended design challenge comprises a major portion of a required first-year engineering (FYE) course at Clarkson University, a small, technologically focused research institution. The course, called Engineering and Society, was developed to satisfy ABET and University-level outcomes and to clarify students' perceptions of the broad socio-technical nature of engineering problem-solving. The course is described more fully in Moosbrugger et al. (2012) and DeWaters et al. (2015).

A series of semester-long, team-based design challenges have been developed, that require students to apply the engineering design process to solve a societally relevant problem. Each challenge culminates with the creation of a working prototype that meets established performance specifications. The projects engage students in self-directed learning and incorporate many teaching and learning experiences that align with EML strategies, including understanding the bigger picture, recognizing opportunities, evaluating markets, and learning from mistakes to create value for themselves and others (Kern Family Foundation, 2022). Since the course was conceived in 2010 we have developed a wide range of design challenges, as shown by the examples in Table 1. The projects are limited in scope to accommodate resource and workspace constraints, making them adaptable to various teaching situations. Materials for prototype construction are confined to recycled or widely accessible items and require only hand tools and adhesives such as hot glue and tape for assembly.

TABLE 1 Sample topics for the team-based design challenge.

Topic	Requirement: design, construct, and demonstrate a prototype …
Snow shovel for 1-handed use	… snow shovel that is appropriate for a user with one functional arm. The shovel must be used with one hand to move a given amount of material within a specified amount of time.
Solar water heater	… passive solar water heater that uses heat generated by a "solar simulator" (a halogen light) to increase the temperature of a given amount of water within a specified time period.
Wind turbine	… bench-scale air-flow turbine to drive a DC generator subjected to a load. The prototype must be designed to simulate real-world applications and be constructed to meet the performance specifications, including a low cost-to-power ratio.
Crash resistant car	… 'crash-proof' automobile constructed with 100% recycled components, which protects passengers (2 eggs) during a simulated crash. The automobile design must include a given set of characteristics similar to a real automobile.
Trans-radial prosthetic arm for children	… prosthetic arm that is appropriate for a 12-year-old child. The prototype is subject to a set of cost and material constraints and must be used to perform a given set of tasks appropriate for the child that will receive it.
Wind-powered car	… automobile constructed with 100% recycled components that will move a given distance using only wind power. The automobile design must include a given set of characteristics similar to a real automobile.

Despite their simplicity, each design challenge enables students to explore first-hand the iterative nature of engineering problem-solving and the importance of collaboration and teamwork to achieve their goals effectively. Through exposure to the myriad sociocultural influences and impacts of technological development, students gain an appreciation of the socio-technical context of the technology they are challenged to develop. A user-centered design thinking approach (Brown, 2008; Leavy, 2010; Daniel, 2016) emphasizes the importance of empathy at the early stages of engineering design to fully understand the user's needs and consider all potential short-and long-term impacts of their proposed solutions. In addition to aligning with ABET's Criterion 3 program outcomes (ABET, 2021), the projects provide opportunities for students to practice EML skills throughout. Projects emphasize Create Value with an insistence on 'understanding/clarifying the problem that needs to be solved' and 'creating solutions that address critical customer needs or local/global problems' as the first and most crucial step in the engineering design process, and the ultimate goal of engineering design, respectively. Students are driven by their own Curiosity to explore multiple perspectives, understand the broader world, and make Connections as they seek new ideas and approaches to their prototype design. Additional connections to the KEEN Framework include Engineering Thought and Action by applying creative systems thinking and examining societal and individual needs; Collaboration through extensive teamwork; and Communication with written and oral project documentation (Kern Family Foundation, 2022).

Project elements are simultaneously mapped to the general flow of the engineering design cycle and the KEEN 3C Framework in Table 2. Teams are assigned using CATME Team-Maker (Layton et al., 2010), an online team management program that creates groups based on a given set of personal data provided through an online questionnaire. After in-class team-building activities that introduce students to the iterative, open-ended aspects of engineering design and the stepwise design cycle approach, student teams complete several organizational tasks to facilitate team bonding and develop effective team dynamics. The creation and use of a team contract helps them establish team norms. Students are required to set goals, individually and as a team; formal assignments throughout the semester require them to reflect on how those goals have been achieved.

An early research assignment guides students through exploring relevant historical and recent technological developments that can impact their prototype design, taking into account their societal context. Their research also helps them develop a deep understanding of the customer, their needs, and the broader context in which their design will be used. Team members use their individual research to inform their ideas as they brainstorm possible solutions using a guided approach that ensures each member's contribution, the 'Idea Trigger' method (Horenstein, 2016). Teams use their research in the first formal deliverable, the Project Proposal, justifying the project's relevance and situating their prototype within a historical context. The Proposal also shares the team's intended approach and plans for completing the project, including a description of their design with sketches, a draft budget, and an overall timeline.

Teams acquire materials and begin the build-and-test process once their Proposal is approved. They continue the iterative steps of building, testing, and revising their prototypes as needed throughout the remainder of the project, working primarily on their own outside of class. Each team is required to submit one Progress Report to ensure that their testing procedures are appropriate for the given set of design parameters and their team is effectively working toward a finished prototype. Teams typically alter their original designs, so updated budgets and drawings are also required, as are structured mid-point check-ins with updated team contracts. Finally, teams prepare and deliver formal presentations that describe their experiences progressing through the design cycle and completing the design challenge. Finalized drawings, budgets, and documentation of the testing results are required components of the presentation. Teams share their working prototypes in a variety of settings, typically involving an open exhibit where each team demonstrates how their prototype meets the given performance objectives.

Students who participated in the action research described here were specifically tasked with designing and constructing a working prototype of an inexpensive, highly functional trans-radial prosthetic arm for children. In addition to being durable, waterproof, comfortable, attractive, and easy to put on and take off by a user with only one functioning arm, the performance specifications required the user to pick up and carry a bucket containing two liters of water a distance of five meters and lift it onto a 1-meter-high table, pick up and move three small objects such as olives or grapes without

TABLE 2 Curricular elements of the design challenge, mapped with KEEN 3C framework.

Project element	Week	Description	KEEN framework
Team formation	1–2	Team building, assigning roles, creating team contracts	Establish connections
Background research	2–3	Exploration of relevant technological developments within a societal context, clarify specific needs of customer/user	Exhibit Curiosity, create value
Brainstorm—formal and informal	3	Structured session facilitated by the instructor, followed by informal brainstorming according to the team's individual needs	Exhibit Curiosity, establish connections
Project proposal	5	Formal team-written report with details of their proposed design	Establish connections, create value
Build and test	6–11	Students construct prototypes, test performance, and revise in an iterative fashion	Exhibit Curiosity, establish connections, create value
Progress report	9	Written communication with the client to update the status and provide project details	Establish connections
Prototype demonstration, presentation	12	Team presentations to share experiences and demonstrate final working prototypes	Exhibit Curiosity, establish connections, create value

destroying their skins, and spread peanut butter onto a slice of bread. The budget was 35 USD.

3.2. Participant information

The study participants were 49 first-year, first-semester engineering students enrolled in two equivalent sections of the Engineering and Society course taught by the first author in Fall 2021. The gender breakdown was 14% Female and 86% Male; the group overall was predominantly (86%) white. All engineering majors were represented, including Aeronautical, Chemical, Civil, Environmental, Electrical, Mechanical, and Undeclared (Engineering Studies).

3.3. Data collection and analysis

Students were asked to complete an online retrospective questionnaire, administered after they had completed the open-ended project. Questions were adapted from the work of Gorlewicz and Jayaram (2020), who used a post-only course assessment protocol to evaluate the impact of a three-course sequence in dynamics and controls on students' self-perceived development of EM skills. Their instrument was created by three instructors, each developing relevant questions aligned with the 3C framework and then vetting them with the other course instructors. The question themes in their instrument parallel the outcomes developed by London et al. (2018), which served as a foundation for the validated Engineering Student Entrepreneurial Mindset Assessment (ESEMA) instrument (Brunhaver et al., 2018). Our adapted questionnaire contains four items to measure self-assessed EM skills related to Exhibiting Curiosity, nine items related to Establishing Connections, and five items related to Creating Value. Each of our items used a 5-part Likert-type scale with one neutral response. The internal consistency reliability of the survey, as measured by Cronbach's alpha, is 0.963, indicating high reliability (Ekolu and Quainoo, 2019).

A total of 48 students completed the questionnaire through an online Google form. Questionnaire data were compiled into Excel and analyzed using SPSS software (Statistical Package for the Social Sciences). Likert-type responses were converted to numerical values (1 to 5) according to a predetermined preferred direction of response to calculate summated rating totals and means for each item. Average responses for each of the three EML constructs were calculated as simple means based on individual student responses to all items in each subscale. In addition to mean values, we determined the positive and negative response rates for each item and each subscale by calculating the percentage of students who strongly or moderately agreed or disagreed, respectively.

4. Results

Student responses to questions within each of the three subscales are shown in Figures 1–3 for Exhibit Curiosity, Establish Connections, and Create Value, respectively. The question stem throughout each subscale asked students to indicate how much they agree that the project assignments helped them improve various engineering-related skills. The average mean scores on all three subscales were between 4 (agree) and 5 (strongly agree), indicating that the socio-technical design challenge successfully improved students' EML skills. Student responses were above a mean value of 4.0 for all items in the Establish Connections and Create Value subscales. Responses were particularly high on Establish Connections items related to teamwork and understanding design applications in the real world. For example, over 75% of the students agreed or strongly agreed that the project was an engaging way to learn and helped them connect information and ideas from various sources and understand real-world engineering design applications. Over 90% agreed that they gained an appreciation for the value and challenges associated with teamwork; over 80% felt they became more efficient working as a team and improved teamwork skills such as information sharing and collaboration.

In the Create Value subscale, almost all students agreed that they gained an understanding of the engineering design process. Over 80% felt the project helped them understand the potential for engineering design to improve societal problems, and over 70% thought it broadened their perspectives for pursuing ethical design practices. Results in the Exhibit Curiosity subscale were less impressive but still good; over 75% of students felt they learned to conduct research, and over 80% felt the project improved their critical thinking compared to lectures. Responses were lowest on items related to self-discovery and

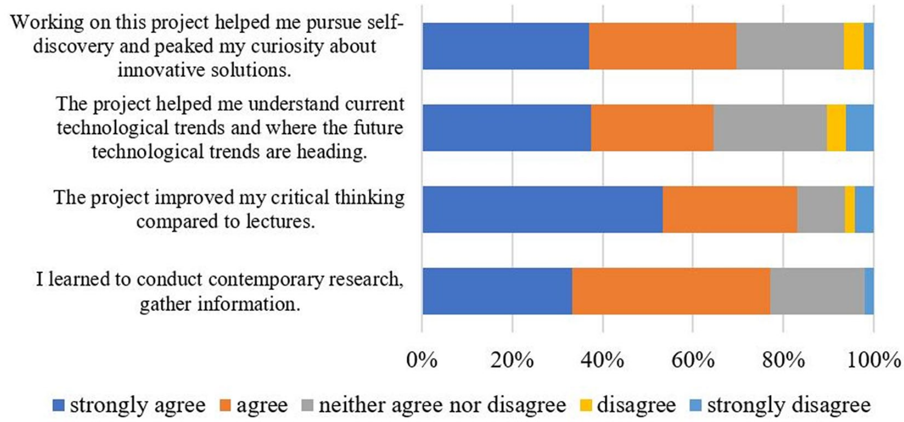

FIGURE 1
Student responses to items in the "Exhibit Curiosity" subscale.

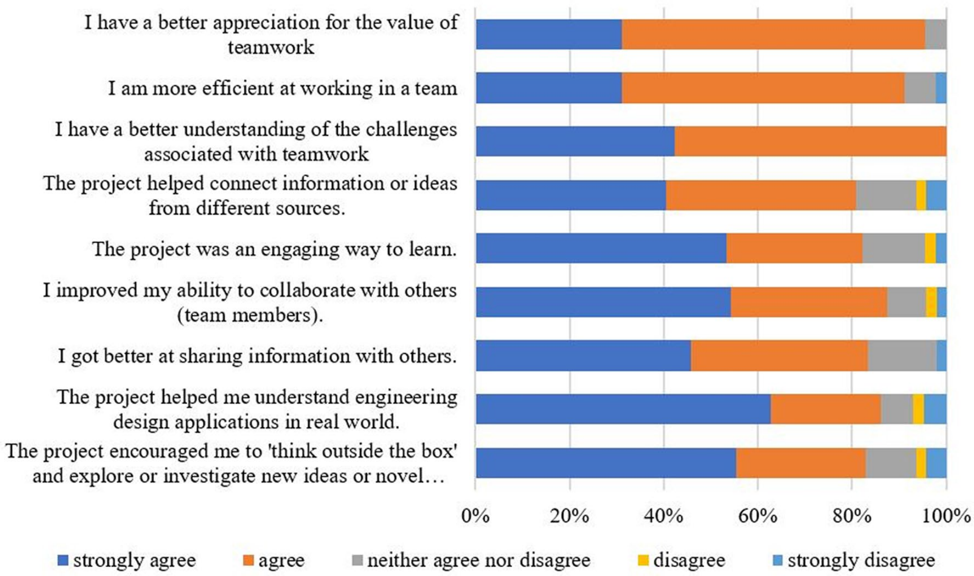

FIGURE 2
Student responses to items in the "Establish Connections" subscale.

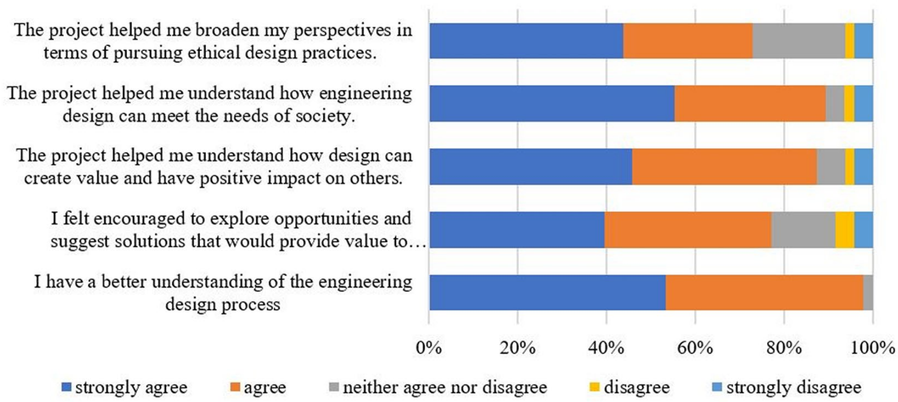

FIGURE 3
Student responses to items in the "Create Value" subscale.

understanding technological trends, the only two items with a mean value less than 4.0. As a result, the average mean response on the Exhibit Curiosity subscale was significantly lower than the mean response on both the Connections subscale ($p < 0.001$) and the Create Value subscale ($p < 0.01$). There was no significant difference between the Establish Connections and Create Value subscales.

5. Discussion and implications

The open-ended, interdisciplinary team-based design challenges described here enable students to experience first-hand the iterative nature of engineering design, the importance of teamwork and collaboration, the need for creativity and empathy, and the complex interplay between technology development and the societal/human context. These relatively simple challenges are situated within a real-world scenario, requiring students to explore the relevance and potential impacts of the technological development and to fully understand the potential user and their particular needs, all strategies that emphasize the socio-technical aspects of design help students appreciate the need to fully comprehend the problem and consider a range of solutions, and increase students' awareness of engineering as a creative and interdisciplinary profession (Moosbrugger et al., 2012; Wedelin and Adawi, 2014; DeWaters et al., 2015; Pucha et al., 2020). The importance of the socio-technical thinking and socio-technical competencies that develop from these types of experiences are widely acknowledged across the engineering education community (Christensen and Ernø-Kjølhede, 2012; ABET, 2021) and are particularly important in a first-year course, given that students often enter university with limited appreciation of the 'human side' of engineering or the importance of communication skills (Karataş et al., 2016).

The interplay between socio-technical design and EML is not widely studied. However, a few investigations found that framing design within a socio-technical context improved students' ability to think with an entrepreneurial mindset and increased their awareness of multiple co-existing solutions to complex problems and the importance of providing value for the user (Bertoni, 2018; Choi-Fitzpatrick and Hoople, 2019). Through our simple retrospective questionnaire, we have added to this evidence. In addition to engaging students in opportunities to develop socio-technical competencies, the socio-technical design challenge used in this research also developed students' EM skills across all three essential qualities defined by the KEEN Framework: Exhibit Curiosity, Establish Connections, and Create Value. The high average mean response to each instrument subscale indicates that students felt they developed skills in all three critical areas of the EML framework. The strongest outcomes were observed for skills related to understanding real-world applications of design and how design can help society, as well as those related to teamwork and collaboration. Overall, average mean responses were significantly higher in the Establish Connections and Create Value categories than in the Exhibit Curiosity category. Over 85% of students agreed or strongly agreed that the project helped them develop skills related to establishing connections and creating value; that rate of agreement was 73% for the aggregated curiosity-related skills. Responses to items in the Exhibit Curiosity subscale varied; for example, 83% of students felt the project improved their critical thinking skills, and fewer than 70% reported that it piqued their curiosity about innovation and helped them understand technological trends.

Several studies have shown broad positive outcomes among students who participate in EM activities, including improved awareness of EML concepts (Blake Hylton et al., 2020), motivation and self-efficacy (Kim et al., 2016; Henslee et al., 2021), and learning beyond the confines of the curriculum (Bosman et al., 2019; Bosman and Fernhaber, 2019). Yet studies such as the one presented here that specifically target EM skill development within the 3C Framework have somewhat mixed results. For example, a study by Zhu (2021) used thematic analysis of project deliverables from a mechanical engineering class that integrated EM content and found that student outcomes were distributed relatively evenly across the 3Cs. Similarly, Bosman et al. (2019); Bosman et al. (2017) found that online discussions developed using the KEEN Framework and specifically designed to increase curiosity positively impacted student perceptions in technical topic areas and increased their curiosity for exploring alternatives and applying new knowledge in other contexts. On the other hand, Jamison (2017) introduced an ideation project intended to instill EM behaviors pertaining to curiosity and creating value in senior engineering students and found that while students developed entrepreneurial skills such as opportunity identification (Exhibit Curiosity) and the ability to effectively "communicate an engineering solution in economic terms" (create value), other behaviors had a negative outcome such as the practice of persistence and learning through failure.

Studies that have used post-surveys like the one used in this research have found similarly mixed outcomes. For example, Santiago and Guo (2018) used a post-survey to assess EM skill development after integrating EML activities into a digital communication systems course. Although students applied a variety of skills in the EML activities, not all skills were developed. Like our study, the post-survey used by Gorlewicz and Jayaram (2020) following the integration of EM content into a multi-course Dynamics and Controls sequence revealed greater development of skills in the Establish Connections and Create Value subscales relative to the Exhibit Curiosity subscale. In our case, the high response rates on items in the Create Value category align with outcomes from student exposure to the links between engineering and society in general, supported by other work (Moosbrugger et al., 2012; DeWaters et al., 2015) and the more general findings by Bertoni (2018) and Choi-Fitzpatrick and Hoople (2019). On the other hand, Curiosity skills would have been most strongly developed during the initial stages of the project (Research and Brainstorm, Table 2), and the time lapse between these learning experiences and the retrospective survey may have partially influenced the low response rates we observed. While we would expect students to develop curiosity skills while engaging in the iterative Build and Test phase of the design cycle, research has shown that novice problem solvers tend to rely more on trial and error compared to those with more experience who tend to spend more time analyzing and exploring ideas before implementing them, questioning data, and referring to past designs as they move forward (Ahmed et al., 2003), all behaviors that would develop curiosity-related skills. Efforts to build a stronger connection during the iterative build-and-test cycle with a continuous exploration of relevant new and innovative technologies may serve to bolster first-year students' curiosity-related skill development.

In summary, students reported positive skill development across all three essential qualities of EML, with more fully developed skills in the Establish Connections and Create Value categories. These EML skills overlap most significantly with the course-and ABET-learning outcomes related to developing students' ability to understand and appreciate the socio-technical context of engineering, which is the primary learning outcome for the project. Essential EM skills related to Create Value echo the approach of design thinking, where 'user-centered' design holds paramount the impact of engineering decisions on key stakeholders, including society, communities, and the environment (Brown, 2008; Kouprie and Visser, 2009), also overlapping significantly with socio-technical thinking. Within Establish Connections, EM skills related to collaboration, information sharing, and real-world connections showed the most significant development. These were fostered throughout the structure and organization of the design challenge. These results suggest that a simple open-ended, team-based design project, when situated in a real-world context and presented to students through a socio-technical, inter-disciplinary lens, can provide students the opportunity to improve their socio-technical thinking competencies and develop their entrepreneurial skills.

6. Conclusion

In response to job market needs and the growing complexity of global challenges, instilling professional skills in students is of utmost importance. With this goal in mind, engineering educators have tried to combine technical and non-technical elements into the engineering curriculum. Teaching engineering as a socio-technical process has positively impacted student skill development. This study proposes a learning innovation, the interdisciplinary team-based design challenge, to better prepare students for the competitive job market and increase their employability. The team-based design challenge described here includes attributes of the design thinking process and KEEN's 3C Framework to instill the entrepreneurial mindset. The results of this study suggest that this learning intervention positively impacted students' professional skill development, their ability to understand and appreciate the socio-technical context of engineering, and the cultivation of an entrepreneurial mindset to discover, evaluate and exploit opportunities. This study offers several contributions. First, it describes a simple yet effective learning intervention that can be introduced into the engineering curriculum as a team-based semester project to develop EM skills. Second, the results from this study show an overlap between the entrepreneurial mindset and socio-technical thinking, which also align with ABET learning outcomes, thus reinforcing best practices for teaching engineering design. While the outcomes of this study are encouraging, several factors limit the interpretation and generalizability of the results. First and foremost is the small sample size of 48 participants. Second, although our survey items were adapted from previous work, a pilot of the items among a broader group would have increased the validity of the questionnaire. Third, we rely on post-only data collection. While this method has clear benefits, a potential downside compared to a pre-test-post-test approach is the possibility of limited recall. Testing both approaches side-by-side in a pilot would help clarify the benefits or drawbacks of either approach. In light of these limitations, future work will include project adaptations to improve students' skill development more broadly across the three critical entrepreneurial mindset elements, accompanied by continuous assessment and evaluation among a larger participant group to test and refine the assessment methodology.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board, Clarkson University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JD taught the course, conceived the study, and was responsible for collecting all assessment data. BK assisted with data analysis, and both authors wrote the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors confirm that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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