First-Year Design Projects and Student Perceptions of the Role of an Engineer

Amanda Singer, Stacie Aguirre-Jaimes, Antonique White, Margot Vigeant, and Michelle Jarvie-Eggart

Abstract*—*Contribution: **This article provides an examination of changes in first-year engineering students' perceptions of the role of an engineer after completing the Engineers Without Borders Challenge.**

Background: **Essential pre- and post-comparisons missing in existing studies on the Challenge are provided, as well as comparison to other first-year project types across two universities.**

Research Question: **Do students who participate in service-learning versus traditional project-based learning gain different understandings of the role of an engineer?**

Methodology: **This work implements the questionnaire variant of convergent mixed methods design. A survey containing a mix of Likert-scale, open-ended short answer, and closed card sorting questions was administered to students enrolled in first-year engineering (FYE) courses across two institutions. Limitations of this work include potential bias due to the pre/post survey design and participant course self-selection.**

Findings: **Students' perceptions of the roles of engineers did not significantly differ by project type. However, changes in their perceptions of technical skills as important to the role of engineers did indicate the beginning of a transition from discipline level thinking to process level thinking. Additionally, course learning objectives influenced students' perceptions of the role of engineers—with an increase in awareness of the importance of problem solving, communication, design process, and teamwork and a decreasing sense of importance of items missing from course objectives, such as creativity and helping people. Engineers' professional responsibility to diversity, equity, and inclusion were absent from both the course syllabi and student perceptions of the role of an engineer.**

***Index Terms*—Engineering profession, learning objectives, project-based learning, service learning (SL).**

I. Introduction

UNIVERSITIES play an indispensable role in the preparation of engineers for professional practice where they are primarily tasked with solving open-ended, complex engineering problems [1]. In fact, preparing students to address these sorts of problems is a requirement of engineering education. Within the United States and abroad, the Accreditation Board for Engineering and Technology (ABET) establishes the criteria for accrediting engineering programs. Under criterion 3, which addresses student outcomes, the "ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics" [2, p. 8] is recognized as an important outcome of undergraduate engineering education. ABET defines complex engineering problems as those that "include one or more of the following characteristics: involving wide-ranging or conflicting technical issues, having no obvious solution, addressing problems not encompassed by current standards and codes, involving diverse groups of stakeholders, including many component parts or subproblems, involving multiple disciplines, or having significant consequences in a range of contexts" [2, p. 7]. Problem-based and service learning (SL) approaches can meet this requirement of enabling students to solve complex and uncertain engineering problems and has been recommended for inclusion in engineering curricula [3], [4], [5]. In addition to building these foundational engineering skills, problem-based learning (PBL) and SL introduce students to real world problems that they may encounter in their future engineering careers. However, little work has examined how engagement with these real world problems impacts students' understanding of the role of an engineer. This study examines the impact of these projects on first-year engineering students' perceptions of the role of an engineer.

II. Background

Threshold concepts are specific concepts that have been identified as a gateway to learning within a specific discipline [3]. As a result, a lack of understanding of threshold concepts can provide learning roadblocks for students. Understanding the roles of engineers has been identified as a threshold concept to the study of engineering [6]. Additionally, as knowledge of a profession influences students' career decisions [7], students' perceptions of the roles of engineers are related to their interest in careers in engineering [8]. For these reasons, understanding first-year engineering students' conceptualization of the role of an engineer, as well as how it changes as a result of first-year engineering education, is relevant for the ultimate success of engineering students within their studies and for their progression into careers as working engineers.

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Research has revealed how engineering students perceive the role of engineers. In 2015, Male and Bennett conducted workshops where they asked undergraduate engineering students to complete individual self reflections on the roles of engineers, finding that most students' responses focused on the technical skills of engineering work. These students also described engineers as being "innovative/creative, knowledgeable, intelligent, leaders, independent, and team players" [3, p. 63]. University instruction has also been shown to impact students' perceptions of the role of an engineer. In 2019, Bielefeldt et al. [9], examined the impact of courses focused on ethics and societal issues by asking students open-ended questions regarding their perceptions of their roles in society as engineers. The most frequent theme within student responses was that of benefiting or impacting society, followed by technology skills and development, ethical obligations, sustainability, concerns for the self (such as financial gain), and obligations to their employers. It should be noted that all of these decreased in frequency of mention after their learning experience, with the exception of ethical obligations and concerns over sustainability, both of which were focused content of the instruction. Additionally, this work included first years through seniors and did not examine the students' understanding of roles as they developed over time in university.

Myers, examined the development of university students' understanding of the role of an engineer, finding that student perceptions of the roles of engineers progress over time in their studies—beginning with discipline level thinking, where engineers are viewed as disciplinary technical experts; progress to process level thinking, with a focus on the roles of engineers in terms of project development and management; and finally evolving into to holistic level thinking, which views engineers at a systems level as working within organizations and society [10]. Most second and third year engineering students in Myers' study had developed process level thinking about the roles of engineers, but were still working on developing holistic level thinking. This progression was credited to two primary elements: 1) the development of students ability to take on the perspectives of others and 2) active learning with a holistic focus to develop an awareness of engineering project constraints and different priorities and perspectives of project stakeholders.

To provide a more expansive understanding of the role of engineers, beyond the technical focus of engineering work (discipline level thinking), engineering programs have been advised to include projects where engineering students work on teams to solve uncertain problems, developing an understanding of the social, economic, and environmental factors [3], [4], [5]. PBL has been well documented to improve students' engineering identities [11], [12], [13]. PBL supports engineering identity development in students, in particular with regards to their internal motivation [11]. Compared to traditional introductory engineering instruction, PBL has been shown to have greater impacts on engineering identity, creativity, and design self efficacy [12]. PBL can also influence younger students, whose identities are more fluid, and has been shown to have a positive influence on the STEM identity of middle school students [13]. Although it is clear that PBL can positively influence students' engineering identity, little work has been done to explore the impact of PBL on students' understanding of the role of an engineer, or what students think engineers do.

A. Problem and Project-Based Learning

PBL was developed to teach Canadian medical students at McMaster University in 1969, ultimately being utilized as an instructional practice in other fields, including law, economics, psychology, and engineering [14]. The abbreviation PBL has been used for both "PBL" and "project-based learning" within the engineering education literature, often with little differentiation between the two [15]. However, "PBL" is focused on new learning while "project-based learning" is focused more on the application of knowledge already acquired [16]. "Project-based learning" also requires student teams to complete a project report [17]. "PBL" involves students being posed with problems for which they must identify learning needs to be addressed through self-directed study—rather than being handed facts and information, students take ownership of their learning [18], [19], [20]. Many FYE projects combine the two. As the projects implemented in this study were all in a first year engineering context, requiring quite a bit of technical research and learning by the students, with the completion of summary reports, this research team considers them to be PBL projects—the definition of PBL operationalized in this work.

Despite early concerns that PBL might not be readily accepted by engineering students [14], engineering and other STEM disciplines have embraced PBL approaches in an effort to include more real-world engineering experiences to students [15]. PBL is particularly suited to encourage students to apply the learned theoretical concepts necessary for addressing the complex engineering problems [21] they will encounter in the workplace, for which there is no single correct answer and a significant amount of work must be done to investigate and understand the problem [1]. Currently, PBL projects are most commonly implemented mostly at the course level [18], and have gained particular popularity within first-year engineering programs and senior design experiences.

SL is a form of PBL that introduces students to course concepts through participation in service projects within a community [22], [23]. As US-based researchers, this research team uses the term SL, while acknowledging that other parts of the world use the term "community engagement" in its stead [24]. Within the US, SL evolved in the 1980's from the cultural beliefs valuing voluntary service [25] and is increasingly being introduced into engineering curricula.

Both PBL and SL have been linked to a wide variety of technical and social learning outcomes. PBL projects increase students' self-reported understanding of the engineering design process and their technical knowledge [15], [26]. PBL not only helps students learn engineering and technical content, these experiences also develop essential professional, or transferable skills, for the engineering workplace. PBL has been shown to increase students' communication skills, their ability to perform research on their own, as well as team work and engineering project management skills [15], [27], [28], [29], Servant-Miklos and Kolmos used a phenomenological approach to discover students' views of PBL as stressful, resulting in interpersonal conflicts, supporting personal growth, a means to both individual and interpersonal academic development, as well as promoting the development of real-world skills [30]. SL has been similarly linked to enhanced student learning and social outcomes, such as increased academic performance, critical thinking skills, increased ability to apply knowledge, and cooperative teamwork abilities [31], [32], [33], [34]. SL offers the additional benefit of fostering a sense of civic engagement in students, developing their abilities to ultimately improve society [35], [36]. SL has also been shown to improve students' perception of their preparedness for engineering careers and studies [37]. A study conducted by Litchfield et al. [38] revealed that engineering students engaged in engineering service through Engineers Without Borders (EWB) USA chapters exhibited significantly higher-perceived professional skills compared to those who did not, with complementary qualitative interviews indicating that this difference was influenced by the real-world and contextualized learning opportunities provided by service experiences. Although the potential student gains from involvement in SL are significant, developing and organizing SL projects requires time and effort on the part of faculty, who may have to work hard to establish community relationships and trust. For this reason, humanitarian aid organizations with established community relationships and partnerships, like EWBs, can be leveraged to provide faculty and students with SL opportunities [39].

B. Service Learning Through Engineers Without Borders

Each year since 2007, EWB Australia has issued a new FYE design challenge in partnership with a community organization. Since its inception, the EWB Challenge has grown and become embedded in engineering programs at universities throughout Australia and New Zealand. Over 100 000 students have participated in the program since its inception [40].

Focus groups of students in Australia and New Zealand who participated in the EWB Challenge documented students' perceptions of the Challenge as an enjoyable experience enlightening students about what engineers can do in the real world, increasing student awareness of sustainability within design decisions, and developing both project group and written communication skills [41]. However, these students also found parts of the projects to be particularly challenging, including developing the information literacy skills necessary for research and improving their team working skills.

In 2014, Colorado State University (CSU) became the first institution within the US to integrate the EWB Challenge into its FYE course structure. Surveys of students who completed the Challenge at CSU found the experience positively affected their understanding of the roles of engineers within society and globally, helped them to see the importance of defining problems, and developed their understanding of how culture affects engineering decisions, including stakeholder needs, especially around problem definition [42].

In 2020, Michigan Technological University (MTU) became the second university within the US to participate in the EWB Challenge. Post-challenge surveys of their students found similar self-reported student outcomes as those reported by CSU [39]. Taken together, these studies indicate that the results were not unique to the universities, instructors, or projects of that given year, but likely a result of participating in the projects. However, it should be noted that both studies only surveyed students at the end of the semester, with no pre-course survey to measure change.

Other evidence exists that participation in SL projects can change student perceptions of the engineering field and the role of an engineer. Shekar examined New Zealand engineering students' self-reported changes in their views of the "role of engineering" as a result of participation in a first-year engineering course implementing the EWB Challenge [41]. Students indicated an increased awareness of: humanitarian engineering, the diversity of roles of engineers, the context for design solutions, environmental impacts, responsibility to society, the engineering process, and the ability of engineers to help others and improve quality of life. Shekar noted that some students did indicate their perceptions did not change.

The CSU [42], MTU [39], and New Zealand [41] studies included only students who completed the EWB project, with no comparisons to students who completed other projects. Additionally, these studies' results were based on end of course surveys inquiring about perceived changes, with no pre-surveys to measure actual changes in students' perceptions of the roles of engineers. To determine if these changes are actually occurring, pre- and post-surveys are needed. Additionally, as no comparison to students completing non-SL projects was performed, questions remain as to whether the changes in students' perceptions of the role of an engineer are unique to the EWB Challenge projects or if they were simply a result of participating in project-based learning. To investigate the implications of the EWB project on student understandings of what it means to be an engineer, the following research question was asked: Do students who participate in service-learning versus traditional project-based learning gain different understandings of the role of an engineer? Preliminary results from the presurveys in this work were presented at the 2022 IEEE Frontiers in Education conference [43]. This article provides a full account of the results of that work.

III. Methods

Constructivist learning theory [44] is employed as a theoretical framing for this work. Constructivist approaches assume that knowledge is created by individuals, which, in turn, is based on one's own experiences and social position. PBL teaching is grounded in Constructivist pedagogy and epistemology [45]. Thus, each student in this study is acknowledged as having constructed their own perception of the role of an engineer. This research reveals the commonalities across those constructions.

The focus of this work is to gain greater understanding of the FYE students' change in their perceptions of the role of engineers based on participation in EWB Challenge projects.

This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination.

TABLE I
FYE DESIGN PROJECTS

Course Offering	Design Project	Students Enrolled	Study Participants
Bucknell University - Fall 2021			
All students complete two of the listed projects.	SUNsational Addition Smart Sustainability App The Power of Ray Building Better Biodigestion Keeping the Fluid Flowing Trash to Cash Making a Building Smart Sustainable Agriculture for the Future	206	75
Michigan Technological University - Spring 2022			
Section 1	EWB AU Design Challenge	95	53
Section 2	Microbrewery Design	166	45
Section 3	Robotics Design	207	71
Section 4	Human Powered Design	178	65

The questionnaire variant of the convergent mixed methods approach [46] was selected to expand upon the quantitative data gathered in previous studies [39], as well as gather additional qualitative data through an open ended question and a closed card sorting survey question, all of which were combined within a single survey administered to FYE students before and after completing their FYE design projects.

A. Participants

Participants of this study included students enrolled in FYE courses across two US institutions in the 2021–2022 academic year. At each of the participating universities, engineering students complete a standard sequence of engineering curricula during the first year of study which includes an introductory-level engineering course. FYE students enrolled in the introductory engineering courses at both institutions are required to complete at least one engineering design project as a part of their final grade. At Bucknell, the required FYE course is taken during their first semester of engineering study (fall semester), during which each student completes two of the projects shown in Table I. These projects span approximately four weeks and center a sustainable interdisciplinary design experience. Their goal is to introduce engineering holistically rather than as a set of specific disciplines. At MTU, the introductory engineering requirement consists of a two-part course sequence that FYE students take during the fall and spring semesters of their first year. Their major first-year design project is completed during the spring semester, with multiple course offerings, each including a different design project. A summary of the FYE design projects that were offered to participants of this study at each institution as well as the number of students enrolled in each section of the course offerings are included in Table I. At MTU, each course offering had a different instructor. Each instructor at MTU and Bucknell was a seasoned first-year engineering faculty with many years of experience teaching PBL. The projects all offer comparable scaffolding with instruction in a design thinking (DT) framework.

Responses were collected only from students who were at least 18 years old and consented to be part of the study. At Bucknell, students enrolled in each of the sections of the required FYE design class in the fall semester of 2021 were invited to participate. Respondents from Bucknell were 64% male, 27% female, 1% nonbinary/other, and 8% of respondents declined to answer. The majority of respondents were white (80%), 11% Asian/Pacific Islander (AAPI), 7% Hispanic/Latinx, with the remaining students identifying as a mixed ethnicity. Only data from students who completed both the pre and post surveys are included in the present study (n = 75, 36.4% response rate). At MTU, students enrolled in the second semester of a required two-part engineering course sequence in the spring semester of 2022 were invited to participate. At MTU, respondents were 58% male, 25% female, and $\tilde{1}$7% declined to answer. Majority of respondents were white (91%), 3% Hispanic/Latinx, 1% American Indian, 1% African American/ Black, 1% APPI, with the remaining students identifying as a mixed ethnicity. Only data from students who completed both the pre- and post-surveys were utilized (n = 234, 36.2%). Note that the previously published work in progress paper [43] included a greater number of participants (152 for Bucknell and 515 for Michigan Tech) as that data set only included the consenting preproject surveys. Some of the students did not complete the post-project survey, resulting in a smaller matched data set for this article.

B. Data Collection

The survey tool utilized in this study included a mix of Likert-scale, open-ended short answer, and sorting questions, administered to participants using Qualtrics. Self-report questions within the survey addressed background demographics, student major choice, the role of an engineer within society, and perceived tasks of an engineer. Additional questions which asked for student-specific information for the purpose of pre–post matching were also included within the survey. Informed consent was obtained from participants for each survey (pre- and post-). Study activities were reviewed by IRB staff at both universities and deemed exempt from full board review at either.

The six Likert-scale questions utilized were developed by others researching the impact of the EWB project at CSU [42]. Previous work by the research team utilized these questions to establish repeatability of results across implementations of the EWB Challenge in first-year engineering programs at different universities [39]. Although these questions were not validated as a survey instrument, to ensure comparability of results across this body of work, these Likert-scale questions were utilized as a part of the data collection for this study.

The questionnaire included seven Likert-scale questions, shown in Table II, asking students to rate their response on a five point scale (i.e., 1—strongly agree, 2—somewhat agree, 3—neutral, 4—somewhat disagree, and 5—strongly disagree). These questions inquired as to whether student see engineers as positive influences on society; having an impact globally; see culture as having an impact on engineering decisions; think problem definition is part of an engineer's job; think time spent communicating is well-spent during engineering design; as well as questions about teamwork.

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TABLE II
SURVEY LIKERT QUESTIONS

Likert Questions	
Q.1.1	I see engineers as positive influences on society.
Q.1.2	I see engineers as having an impact globally.
Q.1.3	I see culture as having an impact on engineering decisions.
Q.1.4	I think "problem definition" is a part of an engineer's job.
Q.1.5	Time spent communicating with people and organizations about their needs, wants, and preferences, is time well spent during engineering design.
Q.2.1	I can function on a team where everyone has their own roles.
Q.2.2	When I am working on a team, I am good at exchanging ideas with teammates.

TABLE III
LIST OF TERMS FOR SORTING QUESTION

Sorting Terms	
an empathizer	skilled at working across disciplines
to define problems	solves problems
an idea generator	helps people
a modeler	works with other countries/cultures
tests prototypes	manages projects
responsible for client/community communication	writes reports
a collaborator with other engineers	delivers presentations
a designer	plans the project
responsible for delivering a prototype	maintains the project schedule
responsible for societal transformation	tracks the project budget
skilled in calculation	is a leader
works on diverse tasks	

This work builds on previous work, which confirmed the results of the CSU study, finding that the EWB project at Michigan Tech had similar results in terms of students indicating a positive effect of the project on their understanding of the role of an engineer, the needs of communities, and the importance of being prepared to work in an international setting [39].

The initial study at Michigan Tech also asked the open ended question "Have your views on the role of an engineer changed as a result of the EWB AU Challenge? In what ways?" and coded the results [39, p. 2]. To provide greater understanding of students' perceptions of the role of an engineer, a closed-card sorting task was selected, with sorting items based on the codes from that previous work. In this manner, student constructions of the role of an engineer guided the development of the closed-ended sorting terms, in keeping with the study's Constructivist approach.

The closed card sorting task asked students to sort attributes according to whether they see them as "very much describes the role of an engineer," "somewhat describes the role of an engineer," or "may or may not describe the role of an engineer." There were 24 potential items to be sorted in this question, shown in Table III. The sorting task required each student to place at least three items into each category (very much describes the role of an engineer, somewhat describes the role of an engineer, and may or may not describe the role of an engineer).

The survey also included the open-ended question "After completing your project, what do you think are the three most important things engineers do in their work?" Respondents were provided a blank space in which they typed their answers.

C. Data Analysis

Results from the quantitative (Likert-scale questions) and qualitative (open ended and closed card sorting survey questions) data were analyzed independently. Prior to analysis, the data collected from both the pre- and post-survey implementations were downloaded from Qualtrics, cleaned to remove any responses missing data, and then matched, resulting in a data set that contained only the matched data for students who fully completed both the pre- and post-surveys. This resulted in full data set for 309 students across the two universities. Quantities for each of the universities and the different project sections are outlined in Table I.

1) Quantitative Analysis: IBM SPSS was used to analyze student responses to each of the Likert questions across the pre- and post-survey implementations. Descriptive statistics for each of the questions were computed for the entire survey population, as well as for the student subset belonging to each university and the different design projects. Paired sample t-tests were used to examine the differences in student responses across the course offering. Specifically, these paired t-tests were used to compare change in mean scores across the measurement period for students belonging to each university as well as the different design projects, providing additional granularity into the variations between sample subsets.

2) Qualitative Analysis: Qualitative data included the open-ended and closed card sorting survey questions. A combined deductive and inductive thematic coding of the open-ended question asking students about their perceptions of the most important things engineers do in their work was performed by undergraduate researchers under the direction of a graduate student researcher supervised by one of the faculty researchers. As part of the Michigan College and University Partnership (MiCUP) Scholars Program, the undergraduate researchers received training in qualitative research through participation in the project. The undergraduate researchers were provided with deductive codes from an existing code book, definitions, and codes developed from previous work [39]. The undergraduate student researchers were trained in how to apply the codes, initially coding along side the research advisors. After being trained on qualitative coding methods and the codes themselves, the undergraduate researchers coded independently. Each interview was coded by multiple researchers. Following each round of student researcher coding, their graduate student and faculty advisors met with the undergraduate researchers to review their coding applications, ensuring that all instances of their coding met with intent and definitions within the code book. Coding differences were resolved by the research advisors. Coding and code books were updated with each cycle of coding until interpretive convergence was met among the researchers [47]. This process is a means of triangulating the results through multiple researchers' viewpoints. The undergraduate researchers were encouraged to develop any new codes as necessary—discussing the definition and application criteria of the new codes with their research advisors, who ultimately had final approval over any code changes. Simultaneous coding methods were used, where multiple codes could be applied to each students' answer to the

TABLE IV
OPEN RESPONSE CODE DESCRIPTIONS AND STUDENT EXAMPLES

Theme	Code (Symbol)	Description of Code	Example from Student Responses
Personal Attributes & Professional Skills	Communication (C)	Communication (between students, students and teaching team, etc.) through written or verbal communication, and presentations. Feedback.	"...create drafts that effectively communicates designs and features of a part, and being able to explain design choices and analysis in creating a prototype."
	Teamwork (TW)	Collaboration with project team, cooperation within the team (easy and difficult people), splitting work load, work within the paid team (excludes clients).	"Teamwork- It is vital that engineers are able to collaborate to express their ideas. One engineer simply cannot do it all. Engineers need to be efficient in teamwork."
	Problem Solving (PS)	Problem solving pertaining to the project, importance of problem solving, how to problem solve.	"Engineers solve problems that help make society a more equitable place."
	Creativity (CV)	Ideas of creativity, importance of creativity in engineering, the act of creating new things, innovate, build/ manufacture.	"...have creative solutions. If engineers weren't creative, we wouldn't have any unique ideas."
Design Thinking	Design Process (D)	General comments about design/design process that do not fit in one of the five Design Thinking categories below.	*"Design, build, tinker"*
	Empathize (DE)	Understanding the needs of the clients, local cultures, being understanding as an engineer, empathizing with communities/people impacted by the project.	"Build empathy and know the community around them and the world."
	Define (DD)	Problem statement, framing the problem.	"Not only find solutions but be able to identify the problem as oftentimes a solution becomes easy after finding the root of the problem."
	Ideate (DI)	Project idea generation, brainstorming.	"Ideate: Come up with designs and concepts never before made."
	Prototyping & Final Products (DP)	Creating prototypes for project, or initial or final products.	"modeling, prototyping, managing"
	Testing (DT)	Presenting prototype to users, feedback.	"Define problems, generate solutions, and test solutions"
Sustainability	Helping People (H)	Helping through engineering work - an individual or a community, greater good, humanitarian work.	"The three things that I think are the most important things that engineers do is help people, improve existing creations, and to build new technology that helps people."
	Sustainability (SU)	Sustainability & environmental concerns, managing social and environmental impacts, waste reduction, considering future generations.	"The environment- Engineers work to save the environment one step at a time. Designing new technology and systems that are sustainable is extremely important to preserve our planet."
	Safety & Ethics (SE)	Keeping safety & ethics in mind.	"Safety of the public- Engineers need to hold the safety of others paramount in their work. Keeping this in mind is extremely important as an engineer."
	Improve (I)	Improvement to pre-existing products and designs, efforts to address quality, efficiency, accuracy.	"Continue to improve their solutions"

question. Codes within each theme, their description, and example quotes are provided in Table IV. In the closed card sorting task prior to completing projects, students typically sorted about 20 terms into categories, while on the post-test, they typically sorted 18 terms. To analyze results within this uneven sorting, we examined the percent of students who selected a particular term. However, caution is advised in interpreting these results as a percentage, as the students sorted 10% fewer terms into categories in the post-survey than in the presurvey. Thus, decreases in prepost sorting of less than 10% may be due to differences in the number of terms sorted.

3) Data Integration and Reporting: The convergent mixed-methods approach was chosen to shed more light on anticipated changes in students' perceptions of the role of an engineer as a result in participating in the EWB Challenge. Similarly, the intent of the data integration was to highlight any changes in the student perceptions of the roles of engineers. After separate analysis of each data set, the research team met to discuss strategies for the combined analysis of the quantitative and qualitative data. The research team settled upon an overall data integration approach of organizing the results of the study around the thematic topics which emerged from the qualitative analysis of the open-ended survey question: Personal attributes/professional skills (including communication, teamwork, problem solving, and creativity), DT (including the overall design process, empathizing with clients, defining problems, ideation, and prototyping/testing/final products) [48], and triple bottom line/sustainability (including environmental, social, and financial impact management) [49]. A breakdown of the closed card sorting terms and Likert-scale questions by these themes is provided in the Appendix. Results from the Likert-scale questions were presented as mean percentages for each section. Significant differences in the mean values are noted within the results tables (alpha of 0.01).

Data transformation can include the quantifying of qualitative data [46], which was considered for each qualitative data type. The research team determined that the results from qualitative open-ended questions would be presented as code counts arranged by central themes found within the data. Although multiple codes could be applied to each response, each code was only applied once per student response. Reports are presented as the percent of respondents within a project type whose answers to the question were coded as such. Codes reported are those found in at least 10% of one or more section's pre- or post-data.

The team also discussed data transformation of the closed card sorting survey results to a final number for each sorted option. However, the original task did not include an ordered ranking, and it was not deemed appropriate to assign a zero value to unsorted answers. Ultimately, those terms sorted by at least half of the responding students into the category of "very much describes the role of an engineer" in their pre- or post-ranking were reported.

D. Trustworthiness

During the semester that the survey was administered to students, one of the co-authors was the instructor of the FYE course offering that completed the EWB Design Challenge as the semester project. To prevent any conflicts of interest, data from the study was not examined until after semester grades were submitted. Additionally, triangulation of data through

TABLE V
THEME 1: PERSONAL ATTRIBUTES AND PROFESSIONAL SKILLS

Evidence	EWB (pre)	EWB (post)	Robot (pre)	Robot (post)	Microbrew (pre)	Microbrew (post)	HPD (pre)	HPD (post)	Bucknell (pre)	Bucknell (post)
Open-ended Coding (% of students with answers including each code)										
Communication	20.0%	25.3%	21.5%	25.9%	46.7%	66.7%	14.9%	21.8%	19.9%	34.5%
Teamwork	21.1%	20.0%	11.4%	22.2%	35.6%	88.9%	11.3%	21.8%	20.5%	27.3%
Problem Solving	37.6%	40.0%	46.8%	46.3%	81.2%	84.1%	39.0%	50.5%	58.3%	36.4%
Creativity	27.1%	16.0%	19.0%	13.0%	43.2%	23.1%	33.3%	20.8%	33.8%	15.5%
"Very Much Describe The Role Of An Engineer" in closed-card sorting task as selected by at least 50% of the students of any section										
Solves problems	77.5%	70.0%	86.1%	72.2%	76.4%	72.7%	86.6%	65.7%	86.7%	80.0%
A collaborator with other engineers	75.0%	50.0%	77.8%	58.3%	74.5%	72.7%	79.1%	61.2%	85.3%	70.7%
Skilled in calculation	52.5%	37.5%	61.1%	37.5%	52.7%	45.5%	50.7%	47.8%	70.7%	44.0%
Likert scale questions (mean value of Likert-scale)										
Q.1.5. Communication	1.15	1.38	1.28	1.38	1.28	1.41	1.37	1.26	1.29	1.17
Q.2.1. Teaming Roles	1.36	1.36	1.29	1.27	1.37	1.28	1.32	1.31	1.32	1.20
Q.2.2. Teaming Ideas	1.43	1.53	1.42	1.38	1.55	1.52	1.55	1.38	1.40	1.40

* Reflects a significant difference between pre and post means (alpha of 0.01).

multiple researchers coding independently was utilized to reduce bias in coding [46], [47].

E. Positionality

As researchers, the team recognizes the vital role that individual researcher identities and experiences play throughout the entire research process [50], [51]. All authors of this work are females. Three of the co-authors possess a background in engineering education research, two as faculty, and one as a graduate student. The team includes the perspectives from the fields of engineering (chemical and environmental), engineering education, and sociology. The research team includes the perspectives of undergraduate students, a graduate student, and faculty.

IV. FINDINGS

As this study employed a Constructivist approach, the meaning constructed by students about the role of engineers informed results synthesis and presentation. Specifically, the emergent themes from the analysis of participant responses to the open-ended survey question asking students what they think engineers do in their work were utilized to organized the presentation of results into the following themes discussed in this section: personal attributes and professional skills; DT; and sustainability.

A. Personal Attributes and Professional Skills

Table V shows the results pertaining to the personal attributes and professional skills of engineering students. For the open-ended question, this includes the following codes: communication, teamwork, problem solving, and creativity. For the closed card sorting task, only the following items were sorted into very much like the role of an engineer by the majority of students: solves problems, a collaborator with other engineers, and skilled in calculation. The results from Likert-scale questions pertaining to communication and teamwork are also included in Table V. Overall, the attributes engineering students found important for engineers were similar across all sections regardless of whether students completed the EWB project or not.

Communication was highlighted in the results in several ways. The coding of the answers to the open-ended question about the most important things engineers do in their work revealed all sections to find communication important. Students' perception of the importance of communication does appear to increase between answers to this question, but the Likert-scale item Q.1.5. (Time spent communicating with people and organizations about their needs, wants, and preferences, is time well spent during engineering design) did not reveal any statistically significant changes from pre- to post-surveys. Additionally, none of the closed card sorting categories pertaining to communication (writes reports, delivers presentations, responsible for client, and community communication) were selected by a majority of students in either of the pre- or post-surveys. Taking this evidence together, the students' perception of the importance of communication was not substantially different after completing the EWB Challenge or other design projects—they all found communication important before and after their projects, but not among those traits they considered as very much describing the role of an engineer.

Teamwork also emerged in the results regarding students' perceptions of the role of engineers. At first glance, it appears that the importance of teamwork decreased slightly in open-ended question responses of the EWB section from pre- to post-project, but increased in all the other sections. However, neither of the two Likert-scale questions addressing teamwork showed any statistically significant differences pre- and post-project for any section. Although it should be noted those questions were assessing the students' perceived skills when it comes to teamwork (Q.2.1—I can function on a team where everyone has their own roles and Q.2.2—When I am working on a team, I am good at exchanging ideas with teammates). Interestingly, the closed card sorting task did show a decrease in the percent of students who thought collaborating with other engineers very much describes the role of an engineer with decreases greater than 10% for all but one section of Michigan Tech (Microbrew). However, even in the post result, at least half the students in each section still agreed with this sentiment. Thus, engineering students entered all sections of their courses with a perception of teamwork as important to the role of an engineer, which

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TABLE VI
THEME 2: DT

Evidence	EWB (Pre)	EWB (post)	Robot (pre)	Robot (post)	Microbrew (pre)	Microbrew (post)	HPD (pre)	HPD (post)	Bucknell (pre)	Bucknell (post)
Open-ended Coding (% of students with answers including each code)										
Design Process	8.2%	32.0%	15.8%	20.4%	20.2%	22.3%	13.5%	24.8%	17.2%	8.2%
Empathize	12.9%	14.7%	7.6%	1.9%	18.9%	7.8%	5.0%	7.9%	4.6%	10.0%
Define	12.9%	29.3%	12.0%	20.4%	16.7%	24.4%	14.2%	26.7%	23.2%	22.7%
Ideate	9.4%	9.3%	7.0%	1.9%	5.6%	4.4%	7.8%	8.9%	3.3%	16.4%
Prototyping	11.8%	2.7%	6.3%	3.7%	5.6%	12.2%	5.0%	7.9%	3.3%	10.9%
Test	3.5%	5.3%	9.5%	3.7%	5.6%	8.9%	2.1%	10.9%	6.6%	6.4%
"Very Much Describe The Role Of An Engineer" in closed-card sorting task as selected by at least 50% of the students of any section										
Responsible for delivering a prototype	32.5%	47.5%	55.6%	43.1%	43.6%	30.9%	41.8%	46.3%	44.0%	53.3%
To define problems	55.0%	45.0%	65.3%	54.2%	65.5%	54.5%	64.2%	56.7%	70.7%	61.3%
An idea generator	67.5%	52.5%	69.4%	59.7%	65.5%	63.6%	80.6%	62.7%	66.7%	69.3%
A modeler	40.0%	55.0%	63.9%	47.2%	52.7%	41.8%	59.7%	46.3%	54.7%	45.3%
A designer	52.5%	67.5%	68.1%	66.7%	81.8%	61.8%	80.6%	64.2%	77.3%	68.0%
Tests prototypes	42.5%	42.5%	65.3%	37.5%	36.4%	40.0%	53.7%	40.3%	68.0%	53.3%
Likert scale questions (mean value of Likert-scale)										
Q.1.4 Problem Definition	1.45	1.4	1.42	1.36	1.38	1.38	1.32	1.23	1.56	1.21*

* Reflects a significant difference between pre and post means (alpha of 0.01).

the students also found important after completing their first year projects.

Two other personal attributes and professional skills emerged from the coding of the open-ended question: problem solving and creativity. The percent of students highlighting creativity decreased for students of all project types. The percent of students mentioning problem solving as among the most important things engineers do in their work increased after project participation for all but the Robotics and Bucknell students. The percent of students sorting "solves problems" as very much describing the role of an engineer did decrease across all sections, but only Robotics and Human Powered Design exhibit decreases greater than 10%. However, in the card sorting results, each term was in competition for selection with the other terms that were provided but did not meet the threshold reporting requirement, resulting in some decreasing. Regardless of this decrease, solving problems remained in the majority for all sections. Both before and after their projects, the students saw problem solving as important for engineering work.

A majority of students also sorted "skilled in calculation" as very much describing the role of an engineer prior to their projects. Across all sections this decreased to less than half for all sections after their projects, with decreases greater than 10% for EWB, Robotics, and Bucknell. This movement indicates a greater understanding of the importance of engineers' nontechnical skills over time in school, and the beginning of progression from Myers' discipline level thinking to process level thinking about the role of engineers. Engineering students' perceptions of engineers are not static, and change throughout their time in college. Research has shown students' perceptions of a good engineer evolve during their studies, as well as how they perceive engineering work. A longitudinal study of engineering students on four campuses found novice students understood the importance of technical skills (discipline level), and with time in school, engineering students gained a sense of the importance of good interpersonal skills (process level) for engineers [52], similarly indicating a progression toward process level thinking. Interestingly, although PBL is known to develop process level interpersonal skills, such as teamwork and communication, their development can be a difficult process for students [41]. SL can develop both process level and discipline level skills, as students also attribute engineering service experiences as a source of development of both their professional and technical skills [53].

B. Design Thinking

Results aligned with the theme of DT are shown in Table VI. The open-ended question codes included in the table reflect the stages of DT (empathize, define, ideate, building prototypes and final products, and test [44]), as well as the overall design process. The closed card sorting items pertaining to DT were selected by more than half the students as very much describing the role of an engineer: responsible for delivering a prototype, to define problems, an idea generator, a modeler, a designer, and tests prototypes. Additionally, one Likert-scale question is reported in this section, asking whether students think problem definition is part of an engineer's job. Overall, the results do not show any major difference between the EWB section and other sections when it comes to DT—students found it important to the role of engineers both before and after the projects, regardless of type of project.

Problem definition emerged several places in the results. The results for the coding of the open-ended question show most sections to place an increase in the importance of problem definition after completing their projects, with the exception of Bucknell students. However, the closed card sorting results show all sections showing a decrease in the percent of students selecting problem definition as very much like the role of an engineer—though only the Robotics and Microbrew sections exhibited decreases greater than 10%. Again, recall that this apparent decrease should be viewed with caution. Changes in responses to the Likert-scale question (Q.1.4—I

TABLE VII
THEME 3: TBL

Evidence	EWB (pre)	EWB (post)	Robot (pre)	Robot (post)	Microbrew (pre)	Microbrew (post)	HPD (pre)	HPD (post)	Bucknell (pre)	Bucknell (post)
Open-ended Coding (% of students with answers including each code)										
Helping People	38.8%	13.3%	22.2%	7.4%	35.9%	24.4%	26.2%	8.9%	15.9%	11.8%
Sustainability	10.6%	9.3%	5.7%	0.0%	13.3%	15.6%	5.7%	5.9%	17.9%	13.6%
Safety and Ethics	14.1%	21.3%	13.9%	5.6%	12.6%	18.2%	11.3%	17.8%	9.3%	22.7%
Improve	30.6%	12.0%	29.7%	20.4%	25.8%	13.8%	25.5%	16.8%	30.5%	18.2%
"Very Much Describe The Role Of An Engineer" in closed-card sorting task as selected by at least 50% of the students of any section										
Helps People	50.0%	45.0%	55.6%	37.5%	45.5%	43.6%	53.7%	43.3%	57.3%	58.7%
Likert scale questions (mean value of Likert-scale)										
Q.1.1. Society	1.21	1.30	1.29	1.22	1.31	1.30	1.28	1.17	1.15	1.25
Q.1.2. Global	1.09	1.17	1.13	1.24	1.20	1.17	1.11	1.09	1.08	1.09
Q.1.3. Culture	1.57	1.43	1.60	1.73	1.62	1.72	1.82	1.48	1.84	1.45*

* Reflects a significant difference between pre and post means (alpha of 0.01).

think "problem definition" is part of an engineer's job) from pre- to post-project were only significant for the Bucknell section data, which moved toward greater agreement with the statement. Considered together, these results indicate that problem definition was an important component of engineering students' perceptions of the role of engineers both before and after their PBL courses.

Comments about the overall design process coded in the open-ended question responses which were not associated with steps in the DT process increased from pre- to post-, with the exception of Bucknell. More students within the EWB section sorted being a designer as very much like the role of an engineer after their project than before—while the other sections decreased after their projects, although only the Microbrew and HPD sections showed decreases greater than 10%. However, even post-projects, the majority of students in each section still sorted being a designer as very much like role of an engineer.

The remaining steps in DT (empathize, ideate, prototype, and test) showed no particular pattern across the open-ended question coding and closed-card sorting items from pre- to post-project across the sections except the closed card sorting of the "tests prototypes" term—which held constant for the EWB section and decreased for all others, although only the Robotics and HPD sections decreased more than 10%. Overall, the most important findings with regards to DT are that, across all sections, students maintained a perception of the importance of problem definition and design both before and after their projects.

The results here align with other work showing the design process, or steps within it, as significant to FYE students' perceptions of the role of an engineer. James et al. [54] asked 150 FYE students to draw their response to the question "what is engineering?". By far, students first thought of engineering as creating and using technologies (77%). Some of the students drew process-based depictions of engineering, such as steps taken in problem solving or to achieve goals (27.6%). Although novice engineering students' have documented grandiose expectations of designing new things as engineers—the working tasks of engineers are often more mundane and these expectations have been shown to became more realistic with time in college [52].

C. Triple Bottom Line—Sustainability

Results presented Table VII pertain to Sustainability or the Triple Bottom Line (TBL)—the economic, social, and environmental risks and benefits which engineers must consider on projects [49]. Coding results of the open-ended question related to TBL include: helping people, sustainability, safety/ethics, and improve. This last code was included in the TBL category as comments within it focused on improvement to pre-existing products and designs in a way that made things better for the future. Only one closed card sorting task item related to TBL was sorted by more than half the students as very much like the role of an Engineer: helps people. Likert-scale questions reported under this theme asked about engineers' influence on society and globally. Question Q.1.3—"I see culture as having an impact on engineering decisions" was also included under the TBL theme. It is acknowledged that considering cultural context is a part of empathy in DT, but it is included in this work under TBL as the question focused on the impact of culture on engineering decisions, not developing client empathy.

Engineers' role in helping people emerged in several places in the results. Both the results from the open ended question coding and the closed card sorting task show a decrease from pre- to post-project of students' perceptions of engineers as helping people, with the exception of the Bucknell card sorting results. However, neither the Likert-scale question assessing students' perceptions of engineers as having a positive influence on society, nor the question about engineers having an impact globally, showed any statistically significant changes pre- to post-project for any section. Finally, it should be noted that within the closed card sorting task neither "responsible for societal transformation" nor "works with other countries/cultures" were considered by the majority of students to be very much like the role of an engineer. Overall, no major differences emerged with regards to the other TBL codes after completing either the EWB or other projects with the exception of the open-ended question code of "improve" decreasing for all sections. Overall, the main finding with regards to TBL concepts is that, regardless of project, engineering students' perceptions of the role of engineers as helping others decreased through the semester. This may be due to high expectations

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for the profession at the start of the their engineering studies.

Student perceptions of engineering as having an impact on society can be a major career motivator. A 2010 survey of 135 FYE students at the University of Memphis found that novice engineering students believe their field of engineering has a significant societal impact, regardless of engineering or engineering technology major. These students also listed the potential to impact society as one of their top three reasons for selecting their major [55]. However, evidence shows students view engineering primarily as impacting society through technologies and infrastructure. James et al.'s study of 150 FYE students found them to understand the designs we make, but only around one in ten of them consider engineering to be focused on global concerns [56]—which is comparable with the percent of responses coded within the theme of Sustainability within the open ended question results in this study. Thus, TBL concerns are something that first-year engineering students do associate with the role of engineers, but not greatly.

V. Conclusion

Prior studies examining the impact of the EWB Challenge on students' perceptions of the role of an engineer were primarily composed of self-reported changes on post-surveys [39], [41], [42]. This study advanced that knowledge by providing essential pre- and post-comparisons to determine actual changes in student perceptions of the roles of engineers, as well as comparing those changes to students completing other types of PBL first year design projects. Considered as a whole, these results do not indicate substantial differences between students completing the EWB Challenge and other first-year PBL projects with regards to their perceptions of the role of an engineer. This work highlights the importance of baseline surveys in measuring change, as well as comparison with other types of projects.

The results of this study show that first-year engineering students acknowledge the importance of personal attributes and professional skills for engineers—especially communication, teamwork, and problem solving. Students of all sections showed a decrease in mentioning creativity in the open-ended question after completing their projects. Additionally, after completing projects of any type, less students thought that the roles of engineers required them to be skilled in calculation—indicating a shift away from a focus on the technical skills in discipline level thinking toward process level thinking about the role of engineers. This work also confirms first-year engineering students' perceptions of design and the DT process components as essential elements of the role of engineers. As first-year students, the bulk majority will not have experienced engineering co-ops or internships, which temper students' expectations when it comes to performing design work as engineers.

Students displayed a decrease in the perception that engineers help people after participating in their projects. Although Sustainability was among the things students thought important for engineering work, it was low on their list. PBL has been proffered as a means to provide engineering students with experiential knowledge and engineering skills needed for engineers of the future, as well as an avenue to integrate the United Nations Sustainable Development Goals into engineering education [56], but instructors with expertise in TBL concepts may be best capable at increasing awareness. In fact, instructor background may matter more than type of project when it comes to influencing students' perception of the importance of TBL within engineers' work. Drain et al. [57], studied the implementation of the EWB Challenge within New Zealand, finding that instructors with expertise in TBL concepts were better able to guide meaningful discussions about the topic with their students.

The themes and codes from the open-ended question within this study were compared with the learning objectives within the syllabi from the courses within this study. Courses at the two universities had similar learning objectives for introductory engineering—with a focus on problem solving, communication, design process, and teamwork. All of these themes can be found in ABET's criteria [3]. Students in this study either gained or maintained a sense of importance of all of these skills, regardless of project type. Interestingly, after completing their projects students within this study displayed a decreasing sense of the importance of creativity and helping people—both of which are absent from the course learning objectives at either university. Overall, the students' perceptions of the roles of engineers were shaped by the course learning objectives, which align with ABET requirements, rather than the project type. This is consistent with the work of Bielefeldt, et al., which found an increase in students' perceptions of ethics as a part of the role of engineers as a result of taking classes where those topics were a focus of instruction [10]. However, research by McNeil and Ohland found that a minority of faculty ascribe to the student-outcome focus within the ABET criteria, but those that do were more likely to align their learning activities with ABET objectives, providing opportunities to learn collaboratively through teamwork [58]. Thus, the faculty within this study may be in that minority.

It should be noted that diversity, equity, and inclusion (DEI), was absent from the coding results of the open-ended questions. It is not surprising that DEI considerations in professional practice are also absent from the course learning objectives. For engineering graduates to take responsibility for making their workplaces more diverse, inclusive, and equitable, DEI must be recognized by students as an essential part of their role as engineers. In fact, future courses will have to address engineers' professional responsibility to DEI, as ABET's Criteria for Accrediting Engineering Programs, 2022–2023, included proposed changes to the General Criteria for Accrediting Engineering Programs—Criterion 5. Curriculum, adding a professional education component that "promotes DEI awareness for career success" [2, p. 52]. Considering this, faculty should pay special attention within curriculum development to aligning course objectives with the desired characteristics and skills of contemporary engineers. Similarly, faculty should take deliberate steps to integrate content and activities into the first-year engineering course and the design projects which actively engage students in activities pertaining to these desired outcomes.

TABLE VIII
THEME ORGANIZATION

	Likert Questions	Open Ended Response Codes	Sorting Terms
Personal Attributes & ProfessionalSkills	Q.1.5. Time spent communicating with people and organizations about their needs, wants, and preferences is time well-spent during engineering design. Q.2.1. I can function on a team where everyone has their own roles. Q.2.2. When I'm working on a team I am good at exchanging ideas with team mates.	Communication Teamwork Problem Solving Creativity Leadership* Questioning* Time Management* Research* Technical Skills* Experience* Work Ethic*	Solves Problems A collaborator with other engineers Skilled in calculation Writes reports* Delivers presentations* Responsible for client & community communications A collaborator with other engineers* Is a leader* Works on diverse tasks* Skilled at working across disciplines* Maintains the project schedule* Plans the project* Manages projects* Tracks the project budget*
Design Thinking	Q.1.4. I think "problem definition" is part of an engineer's job.	Design Process Empathize Define Ideate Prototyping & Final Products Testing	Responsible for delivering a prototype To define problems An idea generator A modeler A designer Tests prototypes An empathizer*
Sustainability	Q.1.1. I see engineers as positive influences on society. Q.1.2. I see engineers as having an impact globally. Q.1.3. I see culture as having an impact on engineering decisions.	Helping People Sustainability Safety/Ethics Improve Cost Consideration* Thinking Ahead*	Helps people Responsible for societal transformation* Works with other countries/cultures*

* reflects an code/sorting item that was identified during analysis or included in the survey itself that did not meet the reporting threshold.

VI. LIMITATIONS

One challenge with a pretest asking students about their perceptions of engineering-related behaviors, attitudes, and skills is that, as FYE students, respondents may not yet understand what terms mean in the same way that they will by the end of the course. Additionally, the students selected 10% less items in the closed card sorting task in the post-test than they did in the pretest. The students at the two institutions were in different semesters, their first in Bucknell, the second at MTU. At MTU, all students self-select into their engineering classes and associated projects. Thus, the data does not represent the impact of the project on a random sampling of students.

APPENDIX—THEME ORGANIZATION

See Table VIII.

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