Critical Pedagogies and First-year Engineering Students' Conceptions of 'What it Means to be an Engineer'

Ms. Ashley R. Taylor, Virginia Tech

Ashley Taylor is a doctoral student in engineering education at Virginia Polytechnic and State University, where she also serves as a program assistant for the Center for Enhancement of Engineering Diversity and an advisor for international senior design projects in the Department of Mechanical Engineering. Ashley received her MS in Mechanical Engineering, MPH in Public Health Education, and BS in Mechanical Engineering from Virginia Tech. Her research interests include broadening participation in engineering, the integration of engineering education and international development, and building capacity in low and middle income countries through inclusive technical education.

Mr. Ben David Lutz, Virginia Tech

Ben Lutz is a PhD student in the Department of Engineering Education at Virginia Tech. His research interests include innovative pedagogies in engineering design, exploring student experiences within design settings, school-to-work transitions for new engineers, and efforts for inclusion and diversity within engineering. His current work explores how students describe their own learning in engineering design and how that learning supports transfer of learning from school into professional practice as well as exploring students' conceptions of diversity and its importance within engineering fields.

Cynthia Hampton, Virginia Tech

Cynthia Hampton is a doctoral student in Engineering Education at Virginia Tech.

Dr. Walter C. Lee, Virginia Tech

Dr. Walter Lee is an Assistant Professor in the Department of Engineering Education and the Assistant Director for Research in the Center for the Enhancement of Engineering Diversity (CEED), both at Virginia Tech. His research interests include co-curricular support, student success and retention, and diversity in STEM. Lee received his Ph.D in Engineering Education from Virginia Tech, his M.S. in Industrial & Systems Engineering from Virginia Tech, and his B.S. in Industrial Engineering from Clemson University.

Dr. Bevlee A. Watford, Virginia Tech

Watford is Professor of Engineering Education, Associate Dean for Academic Affairs and Director of the Center for the Enhancement of Engineering Diversity.

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Abstract

Popular stereotypes regarding the type of work engineers do, the values of the engineering profession, and the types of people that become engineers tend to emphasize technical skills and logical problem-solving—often positioning broader global or societal implications as peripheral, secondary concerns. Though numerous studies of engineering practice run counter to such perceptions, these misconceptions persist nonetheless, creating barriers to participation and often causing engineers to overlook critical factors throughout the design process and when evaluating the impacts of their solutions. Thus, we argue that in order to enhance the quality of both the engineering profession and engineers themselves, learning environments should engage students with content that accentuates the connections between engineering and society and addresses the conflict between popular perceptions and actual engineering practice. One successful approach to creating such learning environments is through the use of critical pedagogies. Albeit underutilized in engineering education, critical pedagogies can engage students with knowledge and ways of thinking that enable thoughtful critique of the systems, rules, artifacts, and other worldly aspects that are often taken for granted.

The purpose of this paper is to explore the ways in which critical pedagogies used during a summer bridge program can influence incoming, first-year college students' perceptions of what it means to be an engineer. Through open-ended entrance surveys and written responses on a final exam, participants were asked to define what it meant to be an engineer. Thematic analysis was used to explore student responses. Findings demonstrate shifts in both students' perceptions of the engineering profession and their own engineering identities. While entry survey responses focused predominantly on notions of problem solving using math and/or science, students' final responses discussed topics such as the importance of collaboration in engineering, the need for diverse thinking, and the broader social impact of engineering decision-making. Students articulated increased interest in, as well as more, comprehensive definitions of engineering. Our results suggest that critical pedagogies, particularly situated in summer bridge programs, may be an effective strategy for expanding perceptions of engineering held by first year engineering students. Furthermore, this research has broader implications for pre-college engineering activities and serves to further the conversation surrounding outreach and recruitment of students in engineering.

Introduction
To the optimist, the glass is half full.
To the pessimist, the glass is half empty.
To the engineer, the glass is twice as big as it needs to be.

We begin this paper with a common joke told about and among engineers. An engineer observes a glass and, in contrast to two others' observations about the level of liquid, decides that the glass is simply too big. The joke here being that while the thoughts of optimists and pessimists are clouded by notions of subjectivity and relativism, the engineer is able to see things as they truly are and make a judgment about—importantly—how things ought to be. The engineer in this joke does not recognize the validity of personal observation or viewpoints in decision-making and instead sees a world that can be objectively experienced and quantifiable. In some ways this joke even implies that both the optimist and pessimist are wrong about their observations, and that the engineer redefines the situation so as to solve the "right" problem. Although seemingly harmless, such a joke has important implications for how engineers and engineering students conceive of their work: engineers not only pride themselves on their logical (read, objective) problem-solving abilities, they eschew subjectivity altogether.

Donna Riley (2008), in her book *Engineering and Social Justice,* points out this joke and others as consequences of potentially problematic stereotypes about engineers' worldviews. Popular notions about the kinds of work engineers do, the values of the profession, and the types of people that become engineers tend to emphasize technical skills and logical problem solving— often relegating social concerns (Riley, 2008). When we think about engineers and what they do, we often conjure up images of "hardcore nerds" who love to apply math and science ("College Majors and Stereotypes, What Does Your Major Say About You?," 2012). They love building and tinkering and making things. They are sitting alone in a lab or with a computer, some equations on a whiteboard behind them. Engineers are often painted in such a light, which not only perpetuates these stereotypes, but can limit the way engineers think about problems and make decisions in everyday practice (Trevelyan, 2010).

Problematic Perceptions
In contrast to popular conceptions, we know from ethnographic and phenomenological research that engineering is a fundamentally social activity (Bucciarelli, 2001). Engineers work together to solve complex problems that have global, societal, environmental, and economic implications (K. Lewis et al., 2011). From observations and interviews, Trevelyan (2010) found that engineers' work is enabled through complex networks within and across departments and organizations, and that cooperative relationships are critical for effective practice. At the same time, however, engineers maintain strict, rigid boundaries around what is—and importantly, what is not—real engineering work (Trevelyan, 2010). Even though practicing engineers spend more time in engaged social interactions (e.g., meetings, phone calls) and coordinating

information (Trevelyan & Tilli, 2008), they consistently describe such activities as "non-engineering." Given the difference between what engineers do and what people *think* engineers do, it is perhaps not surprising that even practicing engineers have conflicting ideas about how they spend their time at work.

These findings are also consistent with ethnographic work with software engineers (Faulkner, 2000). In addition to drawing distinct boundaries around real engineering and social activities, Faulkner (2000) found that engineers also hold implicit values on these different dimensions that value technical skills and relegate social proficiency. Through observations and interviews, Faulkner showed how engineers are prone to dichotomous styles of thought broadly, which prompts them to distinguish between technical and social, specifically (i.e., that which is technical is not social, and vice versa). In this way, to use technical skills is to do "real engineering" while social skills are seen as peripheral and therefore less valuable. Further, by positioning them as opposite poles of a spectrum, Faulkner (2000) demonstrates how these stereotypes almost naturally map onto notions of gender performance, with technical being decidedly masculine and social markedly feminine. Thus, not only do engineers make clear distinctions between what kind of work is important and what is not, they are tacitly assigning gender to different roles and the skills required for them.

One can see how the findings from Faulkner (2000) in the context of those from Trevelyan combine to produce problematic relationships surrounding what is engineering practice and what kinds of skills are valued within it. In other words, if technical and social are seen as opposite ends of a spectrum, and if technical work is perceived as the "real work" then the social aspects of engineering will necessarily be devalued. Further, if this technical/social dualism is inherently gendered, then we can see not only how common stereotypes paint inaccurate portraits of and perpetuate misconceptions about engineering but also how these misconceptions create barriers to participation for those who might not identify with those stereotypical, albeit false, perceptions of the profession.

Changing the Conversation
Trevelyan calls for a re-conceptualization of engineering in ways that position it as "a much broader human social performance than traditional narratives that focus just on design and technical problem-solving" (Trevelyan, 2010, p. 175). Given what we understand about the kinds of work engineers do and the skills needed to solve modern engineering problems, engineers need to understand the broader scope of their practice as well as its impacts within a larger society. In changing the conversation around who engineers are and what engineers do, we can both develop more useful, relevant curricula and in turn, break down some of the popular cultural notions of engineering that perpetuate barriers to entry.

One way to promote these changes in perceptions of engineering is through critical pedagogy. Critical pedagogy has its roots in the philosophical and educational traditions of Paulo Freire, whose work has inspired new and alternative approaches to the "banking model" of education (Freire, 2000). The banking model refers to the structure of education in which knowledge is

positioned as a currency which the professor possesses and which the students seek. In this model, students act as passive receivers of knowledge. Moreover, the knowledge is mostly sought after in order to perform on homework, quizzes, and exams—that is, rarely is knowledge acquired for purposes beyond acquisition and subsequent demonstration (Giroux, 2011). In contrast, critical pedagogies promote student-centered, active learning environments that give students control over their own knowledge creation. By creating a more equitable distribution of power in the classroom, critical pedagogies provide students with opportunities to deconstruct and *critique* knowledge that is often taken for granted (Riley, 2003). Though this approach is more common in humanities, arts, and social sciences, it is precisely the notions of objectivity and positivism rampant in engineering culture that suggest the need for such pedagogies.

The application of critical pedagogy through active and student-centered applications can occur in various environments. However, a shift towards the application of these pedagogies does require consideration of the structure, process, and attitude of the current educational environment. The structures and processes, for example the teaching policies and procedures, can be feasibly introduced into an environment. However, the attitudes of current instructors and administrators to introduce a change, in this case the applications of critical pedagogies, can be much more difficult (Kezar, 2013; Schein, 1985). An environment that encourages the introduction of these types of critical pedagogical structures, processes, and attitudes is needed. One such environment is a summer bridge program designed for students to develop academically, interpersonally, and professionally.

Student Transition Engineering Program
Summer bridge programming is one method of exposing incoming first-year students to their own cognitive habits and practices as well as to the discipline of engineering. This type of programming offers a "bridge" from a student's high school experience to their new experience as a first year university student. This transitional phase can be especially challenging for students depending on their advanced course preparation in high school, study habits, time management, and social adjustment. The Student Transition Engineering Program (STEP) addresses these common issues through a five-week immersive and intensive summer bridge program. The purpose of STEP is to provide incoming College of Engineering (CoE) students (1) an opportunity to become familiar with the university community prior to the start of their academic career, (2) academic enrichment in subjects known to be historically difficult for first-year students at the particular university, and (3) opportunities for personal and professional development. STEP participants take courses in chemistry (lecture + lab), calculus, and engineering fundamentals.

STEP 2016 consisted of 63 incoming first-year students accepted to the CoE. Although not explicitly advertised, some participants had not been accepted into the CoE and had an opportunity to be admitted though their performance in STEP courses. Admittance required obtaining a B or better in all four courses, passing a math readiness exam, and attending all required activities. STEP is run through the Center for the Enhancement of Engineering Diversity (CEED) office and is separate from the first-year program at the current university. Evidence based curricular innovation is welcomed in the development of STEP courses, specifically the engineering fundamentals course. Additionally, this development is supported by

the administrators and instructors of STEP. The curriculum for STEP is revisited every year by the program director and instructors in order to address new needs or areas of improvement, and in conjunction with the first-year engineering courses that the students will encounter during their first semester.

Product Archaeology: Vessel for Critical Pedagogy
Given the goals of the program and the opportunity for curricular innovation within STEP, we developed a 5-week project-based learning course rooted in product archaeology. Product archaeology is a teaching framework that expands on traditional product dissection approaches and provides a space for students to explore the broader impacts of engineering design (Kemper Lewis et al., 2013). In addition to taking apart a product and examining its functions, product archaeology also provides spaces for students to explore the global, societal, economic, and environmental impacts of a particular product design. Similar to archaeologists, students go through phases of the "dig." First, they *prepare* for the dig by conducting background research on the product, answering questions around the initial ideas for the design, the problem it was intended to solve (which might be different from the problem it ultimately did solve). The next phase is *excavation*, where students dissect the product, conduct experiments, and gain a deeper understanding of the different materials and manufacturing processes that combine to create the product. Next, they *evaluate* the product through assessments of the impacts of manufacturing processes, material acquisition, labor costs, and lifecycle management. Lastly, they combine the first three phases to generate *explanations* about how or why the product evolved as it did, how it might continue to develop, implications for alternative solutions, and importantly, a critique of the product itself.

In order to accomplish these goals within the scope and timeline of STEP, we selected disposable razors as the product. Razors were chosen because they 1) represent a product that has undergone significant evolution and engineering refinement; 2) are familiar and likely used by someone on the team; and 3) are often gendered. The object was to use an engineering design product to provide students an opportunity to see the ways in which engineers can and do contribute to societal norms through seemingly "objective" design decisions. In this way, we developed students' awareness of engineering as a social discipline with critical indirect impacts on everyday life. The goals of product archaeology provide a strong foundation on which to develop a classroom and project in which students can think critically both within and about engineering.

Methods
We used qualitative methods to explore how first year students' perceptions of engineering changed during the course of a summer bridge program. When we desire to intimately understand a complex issue, such as changes in students' perceptions of engineering, qualitative approaches serve as a particularly useful research strategy (Creswell, 2009). In order to better understand the ways in which critical pedagogies can influence students' perceptions of what it means to be an engineer, participants reflected on what it meant to be an engineer and how these perceptions changed after STEP. Data were collected using open-ended entrance surveys and

written responses on final exams. Research protocols were approved by the Institutional Review Board (#13-577).

Context and Participants

The research setting was an introductory engineering course embedded within STEP. The course is designed to introduce students to fundamental engineering concepts, and course objectives included engagement with the engineering design process, exploration of engineering disciplines, engineering ethics, technical writing, and problem solving with software tools (Matlab). The course curriculum integrated problem-based learning and product archaeology frameworks (Barrows, 1986; Kolmos, De Graaff, Johri, & Olds, 2014; Lewis et al., 2011). Students were provided scaffolding to explore the global, societal, environmental, and economic impacts of engineering design. Each session of the course included a team-based activity. The five-week course, which met twice per week for 105-minute sessions, was co-taught by two engineering education instructors (both of which are authors on this paper).

Participants in the study included 63 incoming first-year students. The demographics of the group are shown in Table 1. Participants included both students who had accepted fall enrollment for the College of Engineering as well as students who, as noted above, were working to gain admission through their academic performance.

Table 1. Study Participant Demographics

Race/Ethnicity	# of Students	Male	Female	Percentage
Asian	12	12	0	19%
American Indian or Alaska	1	1	0	2%
Black or African American	15	9	6	23%
White (other than Hispanic)	29	21	8	46%
Hispanic/Latino	4	2	2	6%
Two or more	1	1	0	2%
Not Reported	1	0	1	2%

Data Collection

Data collection occurred in two separate sessions of the introductory engineering course. During the first week of the course, open-ended entrance surveys were used to gauge students' prior knowledge and current conceptions of engineering. For the entrance survey, students were specifically asked the open-ended question, "What is an engineer?" The open-ended entrance survey also included short-answer questions on preferred name and pronoun(s), intended major, and particular course topics of potential excitement or concern to students. During the fifth (final) week of the course, participants were asked to reflect on their definition of what it means to be an engineer and how these perceptions changed during STEP. These reflections were written, open-ended responses on the course final exam. Table 2 displays the two prompts used for data collection.

Table 2. Prompts for Data Collection

Timing	Data Source	Prompt
First week of STEP	Written open-ended entrance survey	*What is an engineer?*
Last week of STEP	Written reflection on final exam	*In at least five sentence: explain what you think it means to be an engineer. How has this changed since participating in STEP?*

Data Analysis

Thematic analysis was used to explore, identify, and analyze patterns in data sources while maintaining richness and detail of the students' responses (Braun & Clarke, 2006) Consistent with recommendations from Braun and Clarke (2006), thematic analysis was employed due to its inherent flexibility. Accordingly, a six-phase process for thematic analysis (Braun & Clarke, 2006) was used to analyze data: 1) familiarization with the data through immersion; 2) generation of initial codes; 3) searching for themes; 4) review of themes; 5) definition and naming of themes; and 6) production of report. Data from all 63 participants were analyzed to produce the following study results. Because the responses to the entrance surveys were significantly shorter, we focus primarily on a thematic analysis of the final student reflections.

Limitations

Importantly, we acknowledge several limitations of our work. First, the methods used for collecting data shaped student responses in both richness and content of responses. For the open-ended entrance surveys collected on the first day of the program, student responses were collected as part of a 5-question survey. The prompt was the final of 5 questions, and each question before solicited a markedly short answer response. Surveys were collected on 3 x 5" index cards, which provided little space for students to elaborate on their initial conceptions of engineering. The open-ended survey instrument was implemented for purposes beyond data collection (i.e., getting to know the students), and thus presents a limitation in how students chose to respond.

Further, post-program reflections were collected in the form of written responses on a final exam, which invokes a different type of response than a non-graded open-ended survey. It is possible that students were motivated to respond to the prompt with the "right" answer and not what they actually thought. However, the depth and number of concepts the students were able to articulate is noteworthy, particularly within the context of a five-week summer bridge program. In the written reflections, students thoughtfully reflected on changed conceptions of engineering, which is significant.

Finally, we acknowledge the context of the summer bridge program, which consisted of many experiences that may have changed students' conceptions of engineering identity, engineering values, the engineering profession, etc. For example, one student discussed the impact of a workshop that was independent of curricular content covered in the introductory engineering course. Undoubtedly, the cumulative experience of the summer bridge program – rather than the

introductory engineering course alone –shaped students' beliefs about engineering. We do not claim these findings to be the sole result of the introductory engineering course, but rather offer these findings to contribute to the conversation about outreach and recruitment of students in engineering.

Results

The following sections discuss findings from students' entrance surveys and reflections on a final exam. Emergent themes from the two data sources are contrasted, with a focus on students' rich reflections on a final exam.

Entrance Survey Responses

Students' initial responses on open-ended entrance surveys (Table 3) reflect popular notions of engineering. Students responded to the prompt (*what is an engineer?*) in two distinct ways: what engineers do, in the form of action verbs, and who engineers are, touching on notions of engineering identity. A majority of responses included discussion of engineers as problem-solvers. Several participants used the word "builder" to describe engineers, reflecting the idea that engineers are "tinkerers" and always work with their hands. Other students reflected on the identity of an engineer as one who applies math, science, and logic to solve problems. Student responses often referred to being "efficient" as a central part of being an engineer. Other labels such as "designer", "maker", and "inventor" were also used to describe engineers.

Table 3. Emergent themes in initial student responses.

Theme (Code)	Number of Responses (n=63)	Percent of Responses
Solve problems	38	60%
Designer	14	22%
Helper	11	17%
Builder	10	15%
Use math, science and logic	9	14%
Efficient	6	9%
Maker	2	3%
Inventor	2	3%

Table 4. Codes for Initial Student Responses on Open-ended Entrance Surveys

Theme (Code)	Representative Quotations from Student Entrance Surveys
Solve problems	*Someone who solves the world's toughest problems.* *An engineer is a person that attempts to solve a problem in an innovative way.*
Designer	*Someone who designs… solutions to problems in everyday life.*
Helper	*They use their knowledge to save what we have left of this earth.* *Someone who makes the world better.*

	Someone who uses innovation to make changes and improve lives, situations, and the world!
Builder	*Someone who helps… build structures of the manmade and natural worlds.*
Use math, science, logic, and technical skills	*An engineer is a professional who utilizes scientific and mathematical skills to solve technical issues* *An engineer is a person who uses technical and spatial skills to solve physical problems*
Efficient	*Someone who increases efficiency or improves a method of doing something.* *Someone who creates the most efficient solution to problems.*
Maker	*Someone who can make stuff. Doesn't matter what it is.* *A maker or doer*
Inventor	*One who innovates and invents*

Student Reflections on Final Exam

Compared to entrance survey responses, student reflections on the final exam reflect significant shifts in conceptualization of the types of people engineers are, the types of work engineers do, and the values of the engineering profession. The following sections discuss a narrative of the emergent themes in student responses, which are outlined in Table 5. An important note about Table 5 and the following analysis is that any single response could be assigned multiple codes. For example, responses could—and often did—refer to both engineering identity and their role in society.

Table 5. Prevalence of themes in student reflections on final exam.

Theme	Code	Number of Responses (n=63)	Percent of Responses
Broadened definition of engineering	What engineers do	35	56%
	Engineering identity	12	19%
Interpersonal skills	Collaboration	26	41%
	Diversity	6	10%
	Communication	5	8%
Engineers' role in society	Promoters of human welfare	24	38%
	Engineering ethics	14	22%
	Critical evaluations of engineering	4	6%

Broadened definition of engineering. The most prevalent theme in students' responses was a broadened definition of engineering as a result of STEP. In this study, broadened definitions of engineering refer to an expansion of students' perceptions of the kinds of work engineers do, the type of people engineers are, and the values of the profession. For students, perspectives of

engineering changed on many levels, including perspectives on what type of work an engineer engages in (the engineering profession) and the types of people who can be engineers (engineering identity). In their reflections, students discussed their previous ideas of the engineering profession, which primarily consisted of the engineering profession as an extension, or application, of technical knowledge. Specifically, students reflected that their perceptions of engineering as a profession changed to include "more than math and science".

Students also discussed how their beliefs about what is valued in the engineering profession changed during the program, citing that they no longer believe economic savings are the only aspect of design valued by engineers. Instead, students expanded values of the engineering profession to include global issues, such as accounting for cultural differences during the design process, as well as environmental issues, such as sustainability. The language used to articulate their broadened definitions of engineering closely reflected the curricular focus on product archaeology in the course. In line with the four factors of product archaeology, students' reflections demonstrate understanding of global, economic, societal, and environmental factors of engineering design.

Students' responses included new groups of people in descriptions of who can become engineers, dispelling preconceived ideas about typical engineering identities. For example, students discussed the breakdown of their assumptions about the popular "nerd" and "builder" stereotypes of engineers. One student discussed the differences between their previous beliefs of engineers as "typically non-social people who were only proficient at math and science" and those they hold as a result of participating in STEP, which included constructively using criticism and effectively communicating ideas. Another student discussed their prior belief about engineers as "glorified factory workers," but, through the course and participation in STEP, came to see engineers as "dynamic problem solvers" who engage in "careful planning and out of the box problem solving." Additionally, students shared insights that the identity of an engineer does not inherently emphasize technical skills at the expense, or complete exclusion, of social skills.

Students' responses demonstrate integration of decidedly non-technical skills into their own engineering identities, such as artistic talent or unreservedness, as valuable to the engineering profession. Results demonstrate acknowledgement of multiple ways of being an engineer, emphasizing that no one particular type of person is best suited to be an engineer.

Table 6. Codes for Broadened Definition of Engineering

Code	Representative Quotations from Student Written Reflections
Engineering profession	*To be an engineer a person must know more than math and science, a person must know how to be a civil citizen of society.*
	An engineer does not simply build things, they connect cultures and communities by the things they build and the problems they solve.
Engineering identity	*At the beginning of STEP, I saw engineers as a group of people who built things. They were, in essence, glorified factory workers: they designed and built, with little regard for what they were building*

*and why. I now see engineers as dynamic problem solvers. Instead
of careless building, I see careful planning and out of the box
problem solving.*

*My definition [of engineering] covers a larger range of people. It
can be the socially outgoing or the quiet… the mathematically
brilliant or the artistically gifted. What changed isn't the purpose of
an engineer, but instead the identity of one.*

*…engineers are not restricted to the typical assumptions of a
programmer or builder, but anyone who solves problems…*

Importance of Interpersonal Skills. A second theme that emerged from the data was the importance of interpersonal skills in engineering. In the context of this study, interpersonal skills refer to skills utilized in the process of interacting with other people, such as the ability to work effectively in a team, the ability to communicate with persons from other backgrounds, and the ability to embrace diversity in team settings and beyond. Students reflected on the importance of interpersonal skills in the context of teamwork, saying that "engineers depend on one another" to solve problems and accomplish goals. Many students described teamwork as critical and necessary for effective engineering problem-solving. Some students went as far as to proclaim "engineers don't do things alone", while others identified engineers as "team players".

The importance of teamwork, which we define as being able to collaborate in engineering teams, emerged as a central theme from students' reflections, which is not surprising given the course emphasis on collaborative team assignments. Students discussed collaboration skills as not only beneficial for engineers, but imperative to successfully engaging in the engineering process. One student reflected on the importance of collaboration by saying that "listening to other people's ideas helps create the best final product possible." Many students reflected on the importance of "working together" to solve a common goal, a skill which they deemed necessary for competence in the engineering profession.

Students also discussed the importance of diversity in engineering, particularly noting the utility in having diverse perspectives to solve problems. One student linked diversity on engineering teams as necessary to achieve the "best possible outcome". Another student discussed the value of having "multiple people solving one solution" because of the nature of engineering, which often involves "multiple solutions to every problem". Students discussed many spectrums of diversity, including diversity of experiences, race, gender, and ideas/mindsets. Though discussed less frequently than collaboration, a theme of communication also emerged in students' responses. Several students reflected explicitly on the importance of verbal, peer-to-peer communication in engineering. Most of the discussion on communication was in the context of effectively communicating with members of engineering teams. However, students also reflected on the necessity of communicating effectively with both engineers from other disciplines and non-engineers.

Table 7. Codes for Interpersonal Skills

Code	Representative Quotations from Student Written Reflections
Collaboration	*…I also began to realize the importance of being able to work together with others. Someone can be charismatic or brilliant but still be unable to work effectively with others and that isn't what engineers are.* *…Working well with others is what drives engineers to be successful because listening to other people's ideas helps create the best final product possible.* *I've learned that having another perspective is really important to understanding a problem… you can't do everything alone, and that trying to do that is a lost cause.* *Before came to STEP, I never thought that being an engineer involved collaboration and teamwork. Now I think that is the most important part of being an engineer.*
Diversity	*Being an engineer means working with a diverse group in order to solve a problem. Diverse does not pertain solely to race but to ideas/mindsets.* *There are multiple solutions to every problem, which is why it's valuable to have multiple people solving one solution.*
Communication	*If all engineers could just crank out math problems, without communicating or perhaps offering their own unique perspective towards solving a problem, many problems would remain unanswered!* *Being an engineer means being able to efficiently communicate ideas to others and expand upon those ideas.*

Engineers' Role in Society. Lastly, students offered thoughtful reflections on a shift in conceptions of an engineer's role in society (Table 8). This theme is operationalized in three key ways: engineers as promoters of human welfare, ethical considerations in engineering, and critical reflections on the impact engineers have in society. The most common discussion of engineers' role in society included a conception of engineers as "humanitarians", or persons who are intrinsically motivated to engage in their work as part of a larger effort to make society "better". For example, one student articulated the identity of an engineer as "a particular person [who] is dedicated and determined to better every-day society." In a similar vein, another student reflected that "engineers are people who use their knowledge to help others (animals or people) live in a better way." Interestingly, many students articulated ideas about why practicing engineers are motivated to continue to engage in the profession, saying that "engineers are motivated by the end result of helping others."

Students also offered in-depth reflections on ethical considerations in engineering. Many students noted that prior to the STEP program, they had never considered ethical choices in engineering or consequences of engineering ethics. Students commonly alluded to ethics as a subtle aspect of engineering not previously, or often enough, considered. Interestingly, one student referred to ethics as the "sophisticated" side of engineering, situating ethics as a crucial component of engineering practice. Students most often situated ethics within the context of engineering canons ("Code of Ethics | National Society of Professional Engineers," 2017), which were included in program curricula. Students reflected on their own intentions to refuse to compromise ethics in order to "save money or time."

Perhaps most intriguing were students' critical reflections on the impact of the engineering profession in larger society. While most students viewed engineers as heroes of sorts –using words like "humanitarian" and "helper", other students began to critique and question commonly held beliefs about the inherently "good" nature of engineering. Several student responses deconstructed the idea of engineers' as saviors, noting that engineers can also "change the world… for worse." Another student articulated a thoughtful critique of some engineers' tendencies to "cut corners so they can make a larger profit." Such deconstructions of common knowledge and careful critiques of engineering impact on society align closely with the aims of critical pedagogy, which is to empower students to be active participants in their own construction of knowledge.

Table 8. Codes for Engineers' Role in Society

Code	Representative Quotations from Student Written Reflections
Promoters of human welfare	*Those who become engineers do it because we believe being an engineer will allow us to do good to the world…STEP has helped teach me how to think more like an engineer by not only thinking about the product, but also the lives of others which it will affect.* *…many engineers are motivated by the end result of helping others. I never thought of engineering as a humanitarian subject, but after STEP I saw many ways that engineers used their knowledge to help others.* *…engineers… ensure the health and safety of families all around the world.*
Critical evaluations of engineering	*I think that being an engineer is someone who has the possibility to change the world for better or for worse… it has made me question engineers more, and if they are doing their duty and taking into consideration the impacts of their actions and why they are doing something.* *An engineer also has… to be aware of the possible consequences of his/her design, will it harm the environment, or can it skill someone… engineers are in a position to do good but also evil and not always on purpose.*

	...not all engineers are good and they cut corners so they can make a larger profit.
	Before STEP I didn't think it was an engineers' job to care about things other than the performance of a product... I now realize that to be a good engineer means more than simply solving problems without considering the impact of your solution.
Engineering ethics	*Being an engineer means adhering to a strict ethical code of refusing to "cut corners" to save money or time.*
	...STEP has deepened my interest in engineering and has educated me on the more sophisticated side of engineering, like ethics.

Discussion and Conclusion

Themes identified in students' pre- and post-program responses suggest shifts in conceptions of engineering, including aspects of identity, values, and nature of engineering work. Historically, popular stereotypes of engineering have emphasized technical skills and logical problem-solving at the expense, or exclusion, of societal or ethical concerns. As previously discussed, these misconceptions pose a serious barrier for broadening participation in engineering and compromise the quality of engineering work by excluding critical engineering design factors. Therefore, strategies to change the conversation surrounding engineering (Trevelyan, 2011) become increasingly important.

Through student responses collected at the beginning and end of a five-week summer bridge program, this paper explored critical pedagogies during a summer bridge program and their potential to positively influence students' conceptions of engineering. Using thematic analysis, three themes emerged: broadened definitions of engineering, interpersonal skills, and critical reflections on engineers' role in society. These findings demonstrate shifts in both students' perceptions of the engineering profession and their own engineering identities. Notably, students' conceptions of engineering at the beginning of the program tended to focus on engineering as the application of math and science to solve problems. In contrast, themes of collaboration, inclusive engineering identities, and the social impact of engineering emerged in students' final responses, suggesting a shift in conceptions of engineering.

One of the most interesting themes in student responses was the idea that communication skills are imperative for the engineering profession. Several students reflected explicitly on the importance of verbal, peer-to-peer communication in engineering. Most of the discussion on communication was in the context of effectively communicating with members of engineering teams. However, students also reflected on the necessity of communicating effectively with both engineers from other disciplines and non-engineers. These reflections are particularly interesting in the context of Trevelyan & Tilli's (2008) work, which found that even though practicing engineers spend a majority of their time engaged in communication-related tasks, they do not consider communication tasks to be important. Students' reconceptualization of communication

as an essential engineering skillset offers meaningful implications for engineering career preparation.

In conclusion, this study echoes findings that demonstrate the potential for critical pedagogy to deconstruct prior engineering knowledge, which may be problematic in nature, and critique knowledge that is often taken for granted, such as technical and social dualisms within engineering (Riley, 2003). Results from this study suggest product archaeology, particularly situated in summer bridge programs, may be an effective strategy for expanding perceptions of engineering held by incoming first year engineering students. Encouraging classroom conversations on technical and social dualisms may serve as a means to change the larger conversation surrounding the engineering profession. Additionally, acknowledging that the population of this study were recent high school graduates, the prior engineering knowledge they held was a reflection of the exposure and preparation they received during their K-12 education. This harkens to a deeper conversation on the need for summer bridge programs to provide strategic exposure of the concepts introduced through product archaeology and the program as a whole. Relatedly, this research may enlighten pre-college engineering activities and inform the conversation surrounding outreach and recruitment of students in engineering. Support at various levels is necessary to change the conversation surrounding the engineering profession through critical pedagogy and innovative curriculum. This includes support by program administration to change the curriculum, instructors who want and are prepared to change the curriculum, and students who are in an environment that supports their growth through this change. Without a collaborative and concerted effort by those seeing the necessity for change, students will continue to hold "traditional" beliefs of what an engineer is, what an engineer does, and who is allowed to be an engineer.

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. *Medical Education*,

    20(6), 481–486. https://doi.org/10.1111/j.1365-2923.1986.tb01386.x

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in*

    Psychology, *3*(2), 77–101.

Bucciarelli, L. L. (2001). Design knowing and learning: A socially mediated activity. In *Design*

    knowing and learning: Cognition in design education (pp. 297–314).

College Majors and Stereotypes, What Does Your Major Say About You? (2012, October 1).

    Retrieved from https://www.chegg.com/play/student-life/college-majors-and-stereotypes-

    what-does-your-major-say-about-you/

Creswell, J. (2009). Quantitative Methods. In *Research Designs: Qualitative, Quantitative, and*

    Mixed Methods Approaches. Thousand Oaks, CA: Sage Publishing.

Faulkner, W. (2000). Dualisms, Hierarchies and Gender in Engineering. *Social Studies of Science*, *30*(5), 759–792.

Freire, P. (2000). *Pedagogy of the oppressed*: Bloomsbury Publishing.

Giroux, H. A. (2011). *On critical pedagogy*: Bloomsbury Publishing USA.

Kezar, A. (2013). *How colleges change: Understanding, leading, and enacting change*. Routledge.

Kolmos, A., De Graaff, E., Johri, A., & Olds, B. M. (2014). Problem-based and project-based learning in engineering education: merging models. In *Cambridge Handbook of Engineering Education Research* (pp. 141–160). Cambridge, UK: Cambridge University Press.

Lewis, K., Moore-Russo, D., Ashour, O., Kremer, G., Neumeyer, X., & Chen, W. (2011). Teaching the Global, Economic, Environmental, and Societal Foundations of Engineering Design through Product Archaeology. Presented at the ASEE Annual Conference & Exhibition. Retrieved from https://www.asee.org/public/conferences/1/papers/1149/view

Lewis, K., Moore-Russo, D., Cormier, P., Olewnik, A., Kremer, G., Tucker, C., … Ashour, O. (2013). The Assessment of Product Archaeology as a Platform for Contextualizing Engineering Design, V001T04A024. https://doi.org/10.1115/DETC2013-13165

Riley, D. (2008). Engineering and Social Justice. *Synthesis Lectures on Engineers, Technology, and Society*, *3*(1), 1–152. https://doi.org/10.2200/S00117ED1V01Y200805ETS007

Riley, D. (2003). Employing liberative pedagogies in engineering education. *Journal of Women and minorities in Science and Engineering, 9*(2).

Schein, E. H. Organizational culture and leadership: A dynamic view. 1985.

Trevelyan, J. (2010). Reconstructing engineering from practice. *Engineering Studies*, *2*(3), 175–195. https://doi.org/10.1080/19378629.2010.520135

Trevelyan, J., & Tilli, S. (2008). Longitudinal Study Of Australian Engineering Graduates: Perceptions Of Working Time (p. 13.857.1-13.857.15). Presented at the 2008 Annual Conference & Exposition. Retrieved from https://peer.asee.org/longitudinal-study-of-australian-engineering-graduates-perceptions-of-working-time