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Understanding the Mutual Benefits of University-Elementary School Partnerships on Diversity and Retention in Engineering

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Education

by

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ABSTRACT

Understanding the Mutual Benefits of University-Elementary School Partnerships on Diversity and Retention in Engineering

by

Mandy McLean

The field of engineering continues to be highly male dominated, with women receiving only 20% of undergraduate degrees in the US and comprising only 15% of the workforce. Barriers to entry are experienced by girls as early as age five, when children become cognizant of the stereotype that girls are worse than boys at math. This dissertation sought to understand the barriers to entry and success faced by women in engineering, as well as the types of inclusive instructional pedagogy, from elementary school to college, that could help remove those barriers. We identified the most common barriers through survey data collected from 176 undergraduate engineering students at a university in Southern California. We subsequently analyzed the impact of a novel partnership program developed between a freshman mechanical engineering course and after school elementary program on the participating undergraduates and elementary students. We relied on pre-post student interviews, video-recorded program sessions, and documentation of student work to investigate the elementary students' engineering identities and the undergraduates' self-efficacy beliefs, as they developed over the course of the 10-week program. Three themes emerged from our analysis. First, barriers to entry and success in engineering for women began early and were unrelenting (Chapter 2). Women were introduced to engineering later in their lives and once enrolled in undergraduate programs, women were significantly more likely to have low beliefs in their engineering abilities and expectancies for future success, even after controlling for ability. Second, well designed undergraduate engineering curricula can substantially help boost engineering students' self-efficacy beliefs (Chapter 3). Scaffolded project-based learning helped novice students develop the mastery experiences necessary to feel confident in their abilities and client-led design gave students the opportunity to identify as engineers. Elementary children proved to be ideal clients for freshman engineering students because they simulated the engineer-client relationship in a low-stress environment. Third, highly collaborative engineering programs which leverage peer groups, role models, and inter-group collaboration can help elementary students develop identities as engineers; this was especially impactful for girls (Chapter 4). Working with peers on a collaborative project encouraged students who were initially uninterested in engineering to engage in the activities and engineer role models helped students better identify as engineers. Our work supports and extends the literature by identifying common barriers for girls and women in the field of engineering and analyzing the link between well-designed engineering education and both elementary and undergraduate students' ability beliefs. Our results suggest that to narrow the gender gap in engineering young girls need more regular exposure to engineering in highly collaborative environments and undergraduate engineering programs should be designed to support women's development of engineering competence beliefs through mastery experiences with clear connections to engineering as a career.

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Chapter 1: *Introduction*

"*We must have perseverance and above all confidence in ourselves. We must believe that we are gifted for something, and that this thing, at whatever cost, must be attained."* (Marie Curie)

The overarching goal of this dissertation is to understand how engineering education can be improved to reduce attrition in college and further diversify the population. To achieve these goals, two challenges must be addressed. First, attrition rates for undergraduate engineering programs throughout the US are on the order of 40%, with the highest dropout rates occurring between freshman and sophomore year (Blair, Miller, Ong, & Zastavker, 2017; Busch-Vishniac & Jarosz, 2004; Chen & Soldner, 2014). Second, engineering represents one of the most homogenous of all STEM (Science, Technology, Engineering, and Mathematics) fields: Approximately 80% of engineering undergraduate degrees in the US are awarded to men (National Science Foundation [NSF], 2015). Further, research makes clear that targeting students at the college level to increase diversity in engineering is not enough. Students' interest in STEM prior to high school has been shown to predict their later pursuing STEM careers (Bottia, Stearns, Mickelson, & Moller, 2017; Maltese & Tai, 2011).

The primary context for this dissertation was a partnership between a freshman mechanical engineering course at a university in Southern California and an afterschool program at a nearby public elementary school. The freshman course, *Introduction to Engineering Graphics, CAD and Conceptual Design*, was a ten-week design course required for first-year mechanical engineering undergraduates. Students were expected to learn several foundational skills – free hand sketching, mechanical drawings, computer aided design, laser cutting, soldering, basic microprocessor programming, and the design of basic circuits, motors, and gear trains – to ensure all could successfully complete the final project: to design and build a custom robot that would dance as part of a robot flash mob. The undergraduates were divided into 17 groups of four to five students and each group was paired with two to three elementary students. The elementary afterschool program was held on Friday afternoons for a period of ten weeks. The elementary students served as the customers for the undergraduates: They defined the specifications of the robot, including what it would look like and how it would dance. The elementary students were also partners: They participated in three design team meetings with undergraduate representatives to help create the robot designs and worked independently to build a light-up component that would attach to the robot (e.g., a collar with blinking LEDs for a dog robot). During the interim weeks when the elementary students did not meet directly with their ME10 partners, the afterschool program was led by volunteers from the university chapter of the Society of Women Engineers (SWE). The program concluded with a robot dance performance at the university engineering design showcase; all elementary student partners were invited to attend with their families.

In order to better understand why a gender gap still exists in engineering, the first paper in this dissertation (Chapter 2) sought to identify the types of experiences that were most influential for undergraduate engineering students in selecting an engineering major, as well as the experiences of those students once they began college. We approached this analysis using the expectancy-value theoretical framework with a focus on students' beliefs in their engineering abilities and expectancies for future success; we further compared the findings by gender (Wigfield & Eccles, 2000). The second paper (Chapter 3) expanded on the first through the analysis of the focal freshman mechanical engineering course (described above) designed to increase students' confidence in their abilities through collaborative and scaffolded project-based learning. In an effort to help students feel like professional engineers, the engineering undergraduate students worked closely with clients to design and build dancing robots based on the clients' requested criteria for their final course project. In this paper, we analyzed the impact of the course on the undergraduate students' persistence, resilience, and confidence in engineering through the lens of self-efficacy beliefs (Bandura, 1977). The third and final paper in this dissertation (Chapter 4), grounded in feminism as a movement towards social justice (Brickhouse, 2001), explored the impact of the focal engineering course on the clients, who were fifth- and sixth-grade elementary students. In this final paper, we set forth to understand the role of community, collaboration, and role models on the elementary children's identities as engineers and we, once again, compared the findings by gender. The exploratory nature of this study meant that the research was not grounded in one specific theory, but rather, the papers in this dissertation relied on several different theories to explain the findings. The three guiding theoretical frameworks – expectancy-value theory, self-efficacy theory, and feminism as a movement towards social justice – each lend themselves well to understanding individuals' self-confidence and ability beliefs in a highly male-dominated domain.

The three studies that comprise this dissertation (see Figure 1-1 for summary) serve to fill important gaps in the current literature. First, reasons for the continued gender gap in engineering are unclear. Girls and boys are now completing comparable numbers of mathematics and science credits from elementary school through to high school and girls are commonly earning slightly higher grades, yet fewer girls enroll in advanced high school STEM courses, a trend which continues into college and the workforce (Hill, Corbett, & St.

Rose, 2010; Régner, Steele, Ambady, Thinus-Blanc, & Huguet, 2014). More research is required to understand the barriers commonly faced by girls and women. Second, while there exist progressive engineering courses which incorporate some combination of collaboration, scaffolding, project-based learning, and customer-oriented design, no studies to date explore holistic courses designed around all four of these inclusive instructional practices and further, the impact of these types of progressive courses on students' self-efficacy beliefs (or other related measures) is not adequately researched. Third, there is a dearth of research surrounding the potential for engineer role models to influence elementary students' identities as engineers even though the literature suggests that "modeling is one of the most pervasive and powerful means of transmitting values, attitudes, and patterns of thought and behavior" (Bussey & Bandura, 1999, p. 686). Finally, there is no research available on partnerships between university-level engineering courses and elementary afterschool programs that identify ways that such partnerships support growth in *both* groups. Findings from this dissertation will inform curricular change with data pertaining to how elementary programs and university engineering courses can promote the development of confidence and perseverance in a diverse group of students. This dissertation relied on mixed-methods analyses, utilizing interviews, video data, and surveys to perform both qualitative and quantitative research. The methods employed in each paper are summarized in detail in Figure 1-2.

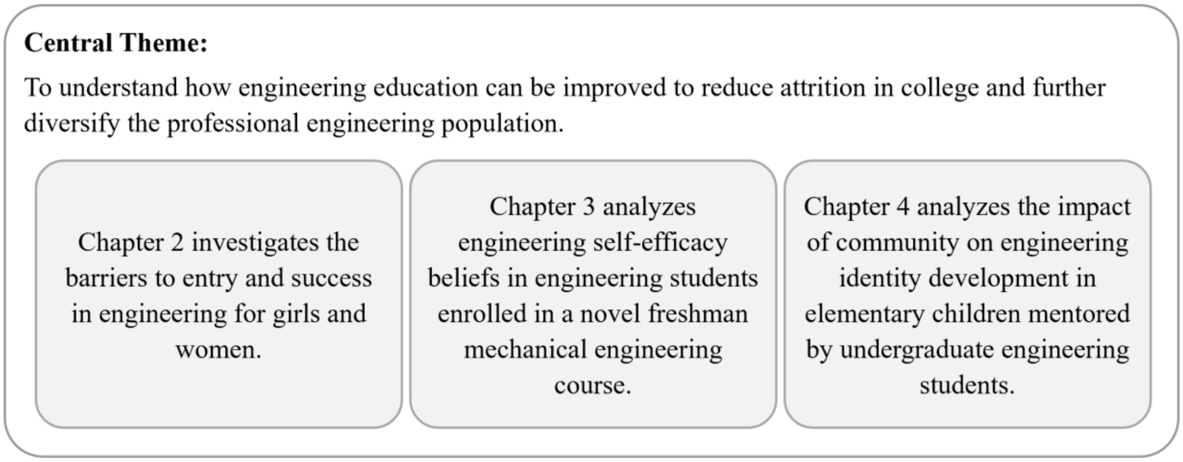

Figure 1-1. Dissertation summary.

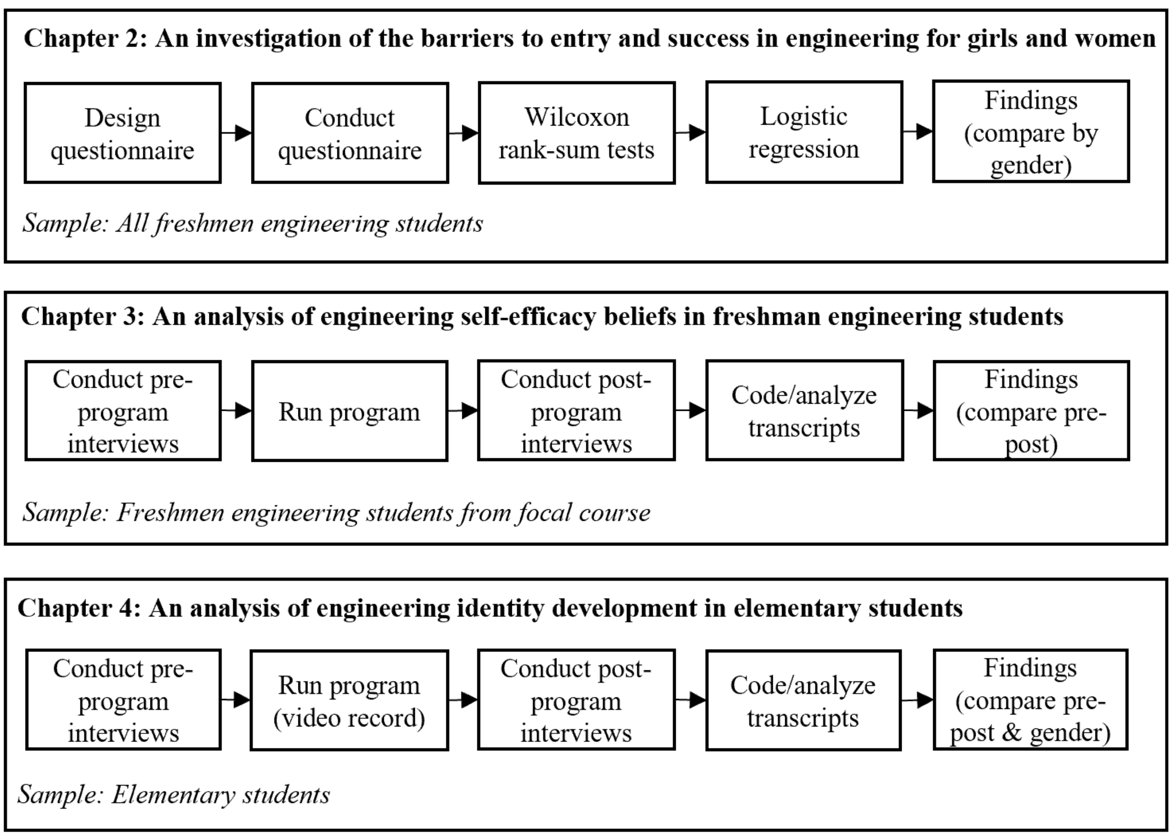

Figure 1-2. Summary of research methods.

This dissertation has been written using a three-paper journal article format; each chapter in the main body serves as an independent article. Chapter 2 will be submitted to the

Journal of Higher Education (JHE); Chapter 3 will be submitted to *Engineering Studies*; and Chapter 4 is under review at the *Journal of Pre-College Engineering Education Research (J-PEER)*. Finally, Chapter 5 concludes this dissertation with summaries of the main findings and contributions to the literature.

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Chapter 2: *An Investigation of the barriers to entry and success in engineering for girls and women*

Abstract

In the highly male-dominated field of engineering, women receive only 20% of undergraduate degrees in the US and comprise only 15% of the workforce. Research suggests that the gender gap in engineering begins as early as kindergarten, when children become cognizant of the stereotype that boys are better at math, and by extension engineering, than girls. And further work has found that confidence and ability beliefs may have a greater impact on career choices than does math performance. This study sought to understand the types of experiences that led students to major in engineering, as well as the experiences of those students in their undergraduate programs. Through the lens of expectancy-value theory, we analyzed students' values for and competence beliefs in engineering, and compared the results by gender. We relied on surveys conducted with 176 engineering undergraduate students to investigate the barriers to entry and success in engineering for girls and women. Two themes emerged from our analysis. First, using a Wilcoxon rank-sum test we found that men were significantly more likely to describe childhood experiences with engineering play as influencing their decision to major in engineering. Women, on the other hand, were significantly more likely to describe experiences with role models later in their adolescence as impacting their choice of major. Second, although women and men were found to have comparable values for engineering, women were significantly more likely to have low beliefs in their engineering abilities and expectancies for future success, even after controlling for ability, demographics, and experiences through a logistic regression analysis. Our work supports and extends the literature by identifying common barriers for girls and women

in the field of engineering, with clear implications for changes to engineering education. Our results suggest that young girls need more regular exposure to engineering and undergraduate engineering programs should be designed to support women's development of engineering competence beliefs.

Keywords barriers; competence beliefs; engineering; gender; stereotypes; values

Introduction

Biological explanations for a gender gap in mathematics have perpetuated the stereotype that boys and men are more capable in mathematics than girls and women and, given the math-intensive nature of engineering, stereotypes in mathematics are typically paralleled in engineering (Hill, Corbett, & St. Rose, 2010). Engineering is one of the most male-dominated of all STEM (Science, Technology, Engineering, and Mathematics) disciplines. Women receive only 20% of engineering undergraduate degrees in the US and comprise only 15% of the workforce (NSF, 2015). There is ample evidence suggesting that societal stereotypes play an important role in observed gender differences in math-based fields (Blickenstaff, 2005; Bussey & Bandura, 1999; Halpern et al., 2007; Hill et al., 2010). For example, the rapid increase in the proportion of high achieving girls in mathematics, from 1:13 in the 1980s to 1:3 in the early 2000s, cannot be adequately explained if nature alone were to account for the gender gap (Hill et al., 2010). The role of nurture, versus nature, in the mathematics gender gap is further supported by empirical studies which have shown that after controlling for past math achievement, high school boys self-assessed their math abilities higher than girls and higher self-assessments increased the odds of enrolling in high school calculus courses and subsequently majoring in STEM fields in college (Correll, 2001). These results point to the possibility that measures of math competence beliefs may have a greater impact on career choices than does math performance.

The gender gap in engineering is concerning for at least four reasons. First, engineers innovate modern society and a diverse workforce is necessary to ensure that they are producing designs that are appropriate for everyone. Second, there is a growing demand in the US for more trained engineers so promoting interest in more women to join these fields can help reduce this shortage of qualified workers (Cheryan, Master, & Meltzoff, 2015; Geisinger & Raman, 2013). Third, engineering is a particularly lucrative field, so women are missing out on competitive salaries. Fourth, male-dominated workplaces can foster environments that are unwelcoming to women, further reducing their presence (Hunt, 2010). While some may argue that the gender disparity in engineering exists because women are simply uninterested in the field, a large body of scientific literature challenges this viewpoint, identifying significant social barriers to girls' and women's entry into engineering (Buck, Clark, Leslie-Pelecky, Lu, & Cerda-Lizarraga, 2008; Cheryan et al., 2015; Stout, Dasgupta, Hunsinger, & McManus, 2011). Until these barriers are removed, we cannot state that the underrepresentation of women in the engineering workforce is due to a lack of interest on their part.

In an effort to better understand why a gender gap still exists in engineering, our research sought to identify the types of experiences that were most influential for students in choosing an engineering major, as well as the experiences of those students once they started their degrees, with a focus on their values and self-perceptions of their abilities. Using survey data collected from engineering students at a university in Southern California, we compared students' experiences across gender and identified potential barriers that may perpetuate the gender gap in engineering today. We approached this analysis through the lens of expectancy-value theory, which suggests that values and competence beliefs are predictive of students' performance and persistence in their chosen fields (Wigfield & Eccles, 2000; Wigfield et al., 2015).

Situating Our Study in the Literature

The threat of fulfilling the deeply rooted stereotype that men are more capable than women in mathematics has been shown to interfere with women's confidence and performance in math-intensive fields (Correll, 2001; Steele, Spencer, & Aronson, 2002). When faced with a situation where one may be evaluated by a stereotype (e.g., a woman in an advanced math class), anything the person does that fits the stereotype (e.g., makes a mistake on a math question) increases the likelihood that she will be continually judged. When this sort of experience generates a fear of confirming a stereotype about oneself, it is referred to as *stereotype threat* (Spencer, Steele, & Quinn, 1999; Steele et al., 2002). Stereotype threat is particularly powerful because it means that stereotypes can affect individuals even before they are judged as the threat of discrimination by one's association with a group that is negatively stereotyped is enough to produce effects of its own. For example, women who perform comparably to men on math tests in non-threatening conditions have been found to underperform in threat conditions—i.e., when told, prior to taking the test, that gender differences were typically observed (Spencer et al., 1999).

Stereotype threat has clear implications for girls' and women's competence beliefs in mathematics and research shows that students are motivated to pursue fields they value and in which they feel confident and competent (Wigfield & Eccles, 2000). However, what leads students to value and feel competent in fields such as engineering is an open question. While we know that experience with engineering is essential—mastery experiences have been identified as one of the most influential sources for increasing students' confidence in their abilities (Bandura, 1986; Geisinger & Raman, 2013)—we do not know for certain what types of experiences are most influential for students who ultimately enter the field of engineering. Studies suggest that women are more influenced by mentors and men are more impacted by intrinsic interest (Kolmos, Mejlgaard, Haase, & Holgaard, 2013; Stout et al., 2011). But this begs the following questions: Why are men more likely to be intrinsically motivated to pursue engineering? Is this nature or nurture at play?

Research around barriers to STEM entry for girls suggests that even adults who encourage non-stereotypical interests often inadvertently contribute to stereotype threat through nonverbal behaviors, such as purchasing more STEM-related games for their sons or interfering more in the math homework of their daughters (Galdi, Cadinu, & Tomasetto, 2014). Thus, it seems possible that boys have more intrinsic interest because they have more exposure to and encouragement in engineering from a young age, while girls, who are less encouraged to engage in engineering early on, only gain experience with engineering later in life, often through exposure to women engineers. In particular, female role models have been shown to be especially impactful for girls and women in engineering because they are demonstrable evidence that women can in fact succeed in male-dominated domains, which undermines negative stereotypes about women's abilities in engineering, decreases stereotype threat, and makes success in engineering seem more attainable (Lockwood, 2006; Marx & Roman, 2002; Stout et al., 2011). In this study, we sought clarity on what influenced students to pursue engineering at the undergraduate level and how these students subsequently perceived their experiences in college and their own abilities and expectancies for success in the future. There is a clear need for more research focused on understanding both the barriers to entry and continued success in engineering experienced by women. Our research provides a first step towards this goal.

Theoretical Framework

The expectancy-value theoretical model posits that people only undertake challenges when they value the work and have some reasonable expectation of success; the perceptions of values and success that they hold are shaped by society (Eccles et al., 1983). Research suggests that, together, people's subjective task values and competence beliefs can explain their level of motivation for persisting in various tasks (Wigfield & Eccles, 2000). Students' values and competence beliefs are thought to develop through experiences of mastery and failure with different tasks, based on feedback from parents and teachers, and through social comparisons with peers (Wigfield & Cambria, 2010). Each of these influencers is tightly linked to societal norms around what is appropriate for girls and boys. As expected per the gender gap in mathematics, empirical studies have shown that boys generally have more positive competence beliefs for mathematics than girls as early as first grade and that competence beliefs in elementary school predict school course, college major, and career choices made many years later (Eccles et al., 1983; Wigfield et al., 2015).

Expectancy value theorists have defined three broad categories of task values: intrinsic value, utility value, and attainment value, and one overarching category of competence beliefs (Eccles et al., 1983; Wigfield & Cambria, 2010). Intrinsic value describes one's level of interest in a task or field, which refers to engineering in this study.

Utility value expresses how useful one considers engineering knowledge to be for their future. And attainment value measures the degree to which one cares about succeeding in engineering. Additionally, competence beliefs is defined by expectancy value theory as comprising one’s beliefs in their present-day engineering abilities, as well as their expectancies for success on engineering-related tasks in the future (Eccles et al., 1993; Wigfield & Cambria, 2010). Expectancy value theory was initially developed to study gender differences in mathematics and Table 1-1 presents the items commonly used in the literature to measure the value and competence beliefs constructs in the domain of mathematics. In this study, we set forth to understand how students’ values for and competence beliefs in engineering vary by gender.

Table 1-1

Items Used to Assess Subjective Task Values and Competence Beliefs in Mathematics on 7-point Likert Scales (Eccles & Wigfield, 1995)

Intrinsic values

1. In general, I find working on math assignments (very boring, very interesting [fun])
2. How much do you like doing math? (not at all, very much)

Utility values

1. How useful is learning advanced high school math for what you want to do after you graduate and go to work? (not at all useful, very useful)
2. How useful is what you learn in advanced high school math for your daily life outside of school? (not at all useful, very useful)

Attainment values

1. Is the amount of effort it will take to do well in advanced high school math courses worth it to you? (not very worthwhile, very worthwhile)
2. I feel that, to me, being good at solving problems which involve math or reasoning mathematically is (not at all important, very important)
3. How important is it to you to get good grades in math? (not at all important, very important)

Competence beliefs

1. Compared to other students, how well do you expect to do in math this year? (much worse than other students, much better than other students)
2. How well do you expect to do in your math course this year? (very poorly, very well)
3. How good at math are you? (not at all good, very good)
4. If you were to order all the students in your math class from the worst to the best in math, where would you put yourself? (the worst, the best)
5. How have you been doing in math this year? (very poorly, very well)

Research Methods

Data Collection

The target sample for this study was incoming engineering undergraduates (freshman and transfer students) enrolled in any of the following departments within the School of Engineering: chemical engineering, computer engineering, computer science, electrical engineering, or mechanical engineering. Surveys were distributed to all students enrolled in a first-year physics course in the spring quarter of 2018. The physics course was required for all first-year engineering students and the surveys were released during the first week of classes. Students were offered extra credit to complete the surveys, however, consent for research was optional and not tied to the credit received for survey completion. After filtering out non-engineering majors, students who did not consent to research, and students who declined to sign waivers agreeing to release their GPAs (a total of 135 students), we were left with responses from 176 students, including 133 men and 43 women. The gender breakdown for this sample, with 24% women, is representative of the field of engineering overall which is comprised of 20% women at the bachelor's level (NSF, 2015). An overview of the students is shown in Table 1-2.

Table 1-2

Student Overview

	Total in Sample	Percentage of Sample
Gender		
Female	43	24%
Male	133	76%
Ethnicity		
White or Asian	141	80%
Underrepresented minority	35	20%
Engineering department		
Mechanical engineering	65	37%
Computer science	43	24%
Computer engineering	27	15%
Electrical engineering	23	13%
Chemical engineering	18	10%
Year in program		
Freshman	158	90%
Sophomore or higher	18	10%
First generation status		
First generation student	55	31%
Non-first generation student	131	69%
Engineering organizations		
Actively involved	76	43%
Not involved	100	57%
Family		
Engineer(s) in the family	69	39%
No engineer(s) in the family	107	61%

Analysis

The analysis for this study was quantitative in nature and proceeded in two phases. First, we analyzed the types of experiences students considered most influential for choosing to enroll in engineering. A multiple-option multiple-choice survey question asked students, Which of the following would you consider influential in your decision to enroll in an engineering program? The responses for the survey question were written to capture experiences from childhood through high school and included experiences playing with engineering-type toys as children, informal experiences with engineering activities (e.g., summer programs or museums), engineering-related classes in secondary school, and encouragement/inspiration from role models or mentors. We then compared the responses by gender using the nonparametric Wilcoxon rank-sum test to identify any significant differences. We also coded open-text explanations in response to the question, Please explain why you chose your current major and be as detailed as possible, based on the multiple-choice response options to provide additional context to students' selections.

For the second phase of analysis, logistic regression was used to help us understand which variables significantly predicted undergraduate engineering students' values and, in a separate logistic regression, competence beliefs in the domain of engineering. All missing data was removed from our analysis using pairwise deletion. In line with EVT research, the values and competence belief constructs were created as the averages of several Likert-type survey items (see Table 1-3). The values and competence beliefs constructs served as the dependent variables in the logistic regression analyses. We measured the reliability of the values and competence beliefs constructs using Cronbach's Alpha which, with alphas of .81 and .78 (acceptable fit >.70) respectively, suggested that the scales had sufficient internal consistency and were reliable for our analyses (Nunnaly, 1978). The Likert-type survey items were each measured on a scale of 1 (strongly disagree) to 4 (strongly agree) and the resulting constructs were reduced to binary outcomes of *high* competence beliefs/values (mean ≥ 3) and *low* competence beliefs/values (mean <3). The independent variables for this analysis consisted of the following: gender, race/ethnicity, GPA, engineering department, year in program, first generation student status, involvement with engineering organizations, and engineer family members. We tested for possible multicollinearity among the predictors by checking the variance inflation factor (VIF), which is the ratio of the variance in the model with multiple terms to the variance in the model with only one term. The VIFs were all less than 2 (acceptable VIF <5) which implied that our model did not suffer from highly correlated independent variables (Akinwande, Dikko, & Samson, 2015).

Table 1-3

Survey Items Used in Values and Competence Beliefs Constructs

V*alues*

1. Engineering is interesting/fun.
2. Engineering is useful for my life outside of school.
3. Engineering is useful for what I plan to do after I graduate.
4. It's important to me that I am good at engineering.

Competence beliefs

1. I feel that I am good at engineering.
2. Compared to other students in my undergraduate program, I feel that I am one of the best at engineering.
3. Compared to most other school subjects, I am better at engineering.
4. With effort, I think I could get even better at engineering.
5. I consider myself to be an engineer.

Note. All questions used a 4-point Likert scale from strongly disagree to strongly agree.

Results

Pre-College Engineering Influences

We asked the undergraduate students in this study which types of experiences influenced their decision to major in engineering and compared their responses by gender. In particular, we probed for different sources of exposure to engineering, including childhood experiences with engineering-type toys, experiences with engineering in informal environments such as afterschool programs or museums, secondary school classes, and encouragement from role models or mentors.

Male undergraduates most commonly described secondary school classes (62%) and childhood toys (52%) as influencing their choice of pursuing an engineering major. Informal settings (33%) and role models (33%) were less influential to this group. On the other hand, female undergraduates most commonly attributed role models (65%) to their decision to study engineering, followed by secondary school classes (48%), informal settings (42%), and finally childhood toys (25%). Employing the non-parametric Wilcoxon rank-sum test, we found that men were significantly more likely ($p < .01$) to describe childhood experiences with engineering-type toys and women were significantly more likely ($p < .05$) to mention role models as influential in their choices of majors.

For added context, as was the case for this male mechanical engineering student, men commonly went on to explain important *early* experiences with engineering:

> Ever since I was a little kid playing with Legos, I've been fascinated by mechanical systems, specifically how they work. It's always been my passion and I've always known that this is what I want to do with my life. So far, I'm really happy with that decision.

Similarly, a male chemical engineering student explained, “My parents always told me they thought I’d be a good engineer because I loved solving science problems and even playing with Legos.”

In contrast, women more frequently described important moments *later in their lives* as adolescents leading them to choose engineering, often as the result of encouragement from role models and mentors in high school. For example, according to one female mechanical engineering student,

> I choose ME [Mechanical Engineering] because of an internship I had over [the] summer. A group of four high school students helped a graduate student in research of voltage-controlled magnetic anisotropy. From this internship, I know I wanted to be an engineer and based on the fun I had in robotics, I choose to be an ME.

Another female mechanical engineering student went on to say,

> I have several strong role models who are engineers and possess excellent creative problem-solving skills. I participated in a high school robotics team, which gave me a taste of engineering. I really enjoyed that experience and wanted to pursue an education and career with similar challenges.

Beyond what influenced these students to enroll in engineering in the first place, we were further interested in understanding how they experienced engineering as undergraduates, in terms of their values and self-perceptions of their ability and expected levels of success. We present our findings from this second part of our analysis in the next section.

Values and Competence Beliefs

Our values logistic regression analysis did not reveal any significant predictors for students' engineering values by gender. Rather, the values construct was heavily skewed towards high engineering values for all students, including both men and women (see Figure 1-1). This is not particularly surprising given that the sample for this study was a group of undergraduate engineering majors at a selective research university. The group of undergraduates, as a whole, clearly placed high value on engineering—they enjoyed engineering, viewed engineering as important to their futures, and cared deeply about doing well in their major.

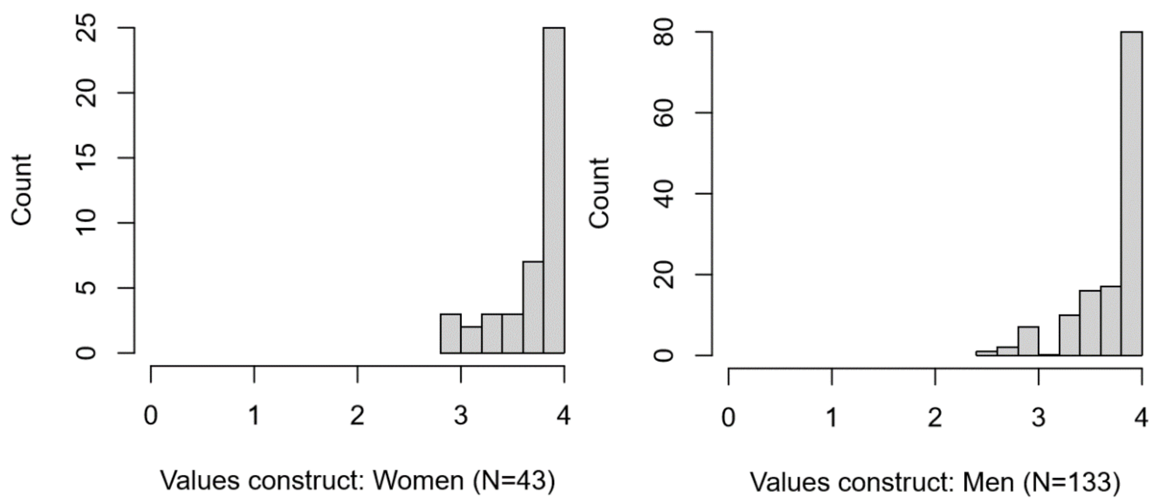

Figure 1-1. Histograms of the Values construct for women and men.

However, it is interesting that even though women and men both highly valued engineering, the competence beliefs logistic regression suggested that gender was the *sole* significant predictor of competence beliefs in engineering, with men significantly more likely to exhibit high competence beliefs in engineering than women (see Table 1-4). In fact, men were nearly three times more likely to have high engineering competence beliefs than women, even after controlling for academic ability (GPA), other demographics (race/ethnicity, first generation student status, engineer family members), and university experiences (department, year in program, involvement in engineering organizations). That is to say that equally capable female engineering students who placed high value on engineering had lower beliefs in their engineering abilities and lower expectancies for future success than their male peers. Research in expectancy-value theory would suggest that these women are less likely to persist in engineering, even though the data indicates that they are equally skilled.

Table 1-4

Logistic Regression Output

			95% CI for Odds Ratio		
Predictor	**β (SE)**	***p*-value**	**Lower**	**Odds Ratio**	**Upper**
Female	-0.968 (0.459)	.034*	0.153	0.380	0.934
Underrepresented minority	0.454 (0.591)	.442	0.509	1.574	5.287
GPA	0.468 (0.585)	.424	0.504	1.597	5.102
Freshman	-1.381 (0.837)	.099	0.035	0.251	1.096
First generation student	0.196 (0.506)	.699	0.452	1.216	3.330
Involved in engineering organization	0.039 (0.414)	.926	0.462	1.039	2.363

Engineer family members	0.455 (0.485)	.348	0.614	1.576	4.164
Mechanical engineering	0.051 (0.689)	.941	0.258	1.053	4.002
Electrical engineering	-0.169 (0.796)	.831	0.171	0.844	4.024
Computer engineering	0.790 (0.830)	.341	0.434	2.202	11.896
Computer science	0.179 (0.782)	.819	0.250	1.196	5.584

Note. $*p < .05$; $**p < .01$; $***p < .001$.

Discussion

The disturbing statistics that women receive only 20% of engineering bachelor's degrees and perform only 15% of engineering jobs indicates a clear need for research related to the barriers to entry and success in engineering faced by girls and women, which are not fully understood today (NSF, 2015). This study provides a step towards better understanding how we can reduce the gender gap by addressing common barriers. We analyzed survey data collected from 176 engineering undergraduate students to better understand which types of experiences led them to pursue engineering and subsequently, upon enrolling in engineering, their self-reported values for and competence beliefs in engineering.

First, the results of our analyses suggested that the experiences which led female and male undergraduates to major in engineering were notably different. The men in our study were more commonly driven to pursue engineering from a young age, citing childhood play with engineering toys as highly influential in their choice of majors. On the other hand, the women in our study described their most influential experiences with engineering as occurring later in adolescence, noting the importance of mentors commonly introduced during their high school years. It is vital that we encourage young girls to also engage with engineering as we know that gendered attitudes towards mathematics are currently evident to children as early as kindergarten and automatic stereotype associations are strengthened through repeated exposure to stereotype-aligned behaviors (Ceci, Ginther, Kahn, & Williams, 2014; Galdi et al., 2014).

Second, we found that while female undergraduate students held comparable values for engineering to their male counterparts, they were significantly more likely to have low beliefs in their engineering abilities and low expectancies for success in their futures, even after controlling for academic ability, demographics, and experience. In fact, gender was the *only* significant predictor of competence beliefs in undergraduates. Based on expectancy value theory research, this implies that these women, who are as capable as their male peers, are less likely to persist in the field of engineering. These findings also align with research on stereotype threat, which shows that the threat of being judged based on a stereotype can interfere with women's confidence in their abilities (Steele et al., 2002). Fortunately, stereotype threat research offers hope for helping females overcome these debilitating effects, including teaching about stereotype threat and promoting a growth mindset. Interventions that teach about the phenomenon of stereotype threat have been shown to help individuals attribute their anxieties to stereotype threat as opposed to low ability. In addition, teaching that one becomes successful through hard work and perseverance, as opposed to innate ability, supports a growth mindset which has also been shown to counter the negative impacts of stereotype threat (Hill et al., 2010; Shapiro & Williams, 2012; Steele et al., 2002).

In sum, the results from our study suggest that delayed exposure to engineering remains a prevalent barrier for women in entering the field of engineering. Even for those who decide to enroll in engineering, lingering stereotypes lower women's beliefs in their engineering abilities and expectancies for success. There is a clear and immediate need to both encourage more young girls to engage in engineering and to help female undergraduates persist in engineering by taking action to help them believe in their own abilities.

Conclusions

Our study set out to understand the most influential experiences leading students to enroll in engineering and subsequently, the experiences of those students in their undergraduate programs. Through the lens of expectancy-value theory, we analyzed students' values for and competence beliefs in engineering using survey data from 176 engineering undergraduates. We compared our findings by gender in an attempt to learn more about potential barriers for girls and women in entering and succeeding in the highly male-dominated field of engineering. We found that men were significantly more likely to attribute childhood play as highly influential in their decisions to pursue a degree in engineering, whereas women more commonly described role models introduced later in their adolescence. Upon enrolling in an engineering undergraduate program, women and men held comparable values for engineering, however, even after controlling for ability, demographics, and experience, women had significantly lower beliefs in their engineering abilities and expectancies for future success in engineering.

Our findings provide an important step towards better understanding the barriers girls and women face in entering and succeeding in the field of engineering. Girls, even those who go on to major in engineering, are less likely to engage with engineering play than boys, which both reaffirms the stereotype that engineering is for boys and creates a gender gap in engineering experience. Further, upon enrolling in engineering undergraduate programs, women have lower competence beliefs, which indicates that they are less likely to persist in the field. As such, it is important that we work to ensure that girls are exposed to engineering from a young age and that we design undergraduate programs to support women's growth, which typically means addressing the stereotype that women are less capable in engineering head on and encouraging a growth mindset. Our conclusions are limited by our sample size—in particular, the low ratio of women to men. However, this circles back to the very issue we wished to address in the first place: Not enough women are majoring in engineering. Action is required on the part of engineering educators, from elementary school through college, to help close the gender gap.

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Chapter 3: *"I feel a little more engineery": An analysis of self-efficacy in freshman engineering majors*

Abstract

Engineering undergraduate programs in the US commonly experience over 50% attrition, with the highest dropout rates occurring between freshman and sophomore year. Researchers in the field of engineering education have identified low self-efficacy as a main driver for attrition. And according to self-efficacy theorists, mastery experiences are the most influential source of self-efficacy. This qualitative study analyzed the impact of a redesigned freshman mechanical engineering course on students' self-efficacy beliefs. The quarter-long course, designed to support students' learning and scaffold skill development, culminated in a final project which required students to design and build dancing robots to the specifications of a group of elementary children, who served as their clients. We relied on pre- and post- quarter interviews with 10 freshman students to investigate students' changing engineering self-efficacy beliefs. Two themes emerged from our analysis. First, through scaffolded hands-on lab sessions, students developed the skills necessary to complete rigorous final projects on their own and these mastery experiences contributed to increased self-efficacy beliefs. Second, the elementary children proved to be effective clients for freshman engineering students for several reasons: They simulated the engineer-client relationship in a low-stress environment, they were more accessible than industry clients, and they also benefited from the experience. Our work supports and extends the literature in engineering education by analyzing the link between well-designed engineering curriculum and engineering students' self-efficacy beliefs. Our results suggest that scaffolding client-led design projects in freshman engineering courses helps to foster self-efficacy beliefs through mastery experiences with clear connections to engineering as a career.

Keywords client-led design; collaboration; engineering; freshman courses; project-based learning; self-efficacy

Introduction

Research suggests that not enough students are graduating with engineering degrees from college to meet the growing need for qualified engineering professionals in the US and throughout the rest of the world (Geisinger & Raman, 2013). Low enrollment rates further amplified by high rates of attrition contribute to the current paucity of engineering graduates. Attrition for undergraduate engineering programs throughout the US is on the order of 40 to 70%, suggesting that nearly, and sometimes more than, half of the students entering engineering programs leave before graduating (Blair, Miller, Ong, & Zastavker, 2017; Busch-Vishniac & Jarosz, 2004; Chen & Soldner, 2014; Geisinger & Raman, 2013).

Freshman year is a critical year for engineering students and is where we typically see the highest rates of dropout (Knight, Carlson, & Sullivan, 2007; Moller-Wong & Eide, 1997). This can be attributed, in part, to the nature of the first-year curriculum. Gatekeeper freshman engineering courses are notoriously difficult and have been criticized for offering little connection to engineering as a career; they are instead designed to weed out students who are considered unlikely to succeed in engineering (Busch-Vishniac & Jarosz, 2004; Chesler & Chesler, 2002; Knight et al., 2007; Seymour, 1995). However, the ability of these gatekeeper courses to accurately distinguish between those students who will be successful engineers and those who will not is debatable. Researchers have identified low self-efficacy as one of the main factors driving students to leave engineering and mastery experiences as the most influential source for increasing self-efficacy (Bandura, 1986; Geisinger & Raman, 2013; Kirn & Benson, 2018; Moller-Wong & Eide, 1997; Snyder, Barr, Honken, Pittard, & Ralston, 2018). This suggests that gatekeeper courses, which give excessively difficult exams and fail to provide opportunities for mastery experiences relevant to engineering careers, are potentially driving away students who could be successful engineers but lack self-efficacy because they have not yet been given the opportunity to realize their full potential.

Our research set forth to investigate the impact of a redesigned freshman mechanical engineering course on students' self-efficacy beliefs. This course was redesigned to support student learning and the development of mastery experiences in a highly relevant project-based environment with clear connections to engineering as a career. Through scaffolded lab sessions spread throughout the quarter, students developed the skills necessary to successfully complete their final course projects. In an effort to help students feel like professional engineers, they were given the opportunity to work closely with clients, for whom they developed products, throughout the quarter. The clients in this course were elementary children. Collaboration among peers and between the students and their clients was integral to the success of these projects. Using data collected through pre- and post-quarter interviews with a subset of 10 freshman students enrolled in this course, we attempted to answer the following research question: What impact did this course have on the freshman engineering students' engineering self-efficacy beliefs?

Situating Our Study in the Literature

The highly competitive nature of the undergraduate engineering experience has been found to negatively impact the well-being of students, especially women and other minorities who often feel isolated because of their underrepresentation (Busch-Vishniac & Jarosz, 2004; Geisinger & Raman, 2013; Goodman et al., 2002; Seymour & Hewitt, 1997). While most engineering programs entail group work and teaming experiences, these are typically found in the latter years, such as in senior capstone courses. Courses that demonstrate value for collaboration in the freshman year have been found to contribute to reduced feelings of isolation and an increased sense of belonging, leading to higher rates of retention in engineering programs (Grandy, 1998; Suresh, 2006). Similarly, these collaborative upper-level courses tend to center around project-based learning (PBL), in contrast to lower-level gatekeeper types of courses. Research on PBL suggests that hands-on project-based courses increase student retention and diversity, as compared to more traditional lecture-based courses, because PBL creates more individualized learning opportunities and mastery experiences (Busch-Vishniac & Jarosz, 2004; Dym et al., 2005; Kilgore, Atman, Yasuhara, Barker, & Morozov, 2007; Knight et al., 2007).

Well-executed project-based courses in engineering help to bridge the gap between the theoretical and the real world through clear connections to engineering as a career (Froyd, Wankat, & Smith, 2012). Providing a series of increasingly complex, or scaffolded, projects helps to support students' learning while they gain the skills necessary to complete larger and more difficult projects on their own (Crismond, 2011) and client-led design, whereby students design projects to meet the needs of clients, helps provide first-year engineering students a more authentic engineering experience (Dym et al., 2005).

In an effort to understand why so many engineering majors leave the field before graduating, researchers have identified students' self-efficacy beliefs as an important predictor of persistence (Geisinger & Raman, 2013; Lent et al., 2003; Leslie, McClure, &

Oaxaca, 1998; Schaefers, Epperson, & Nauta, 1997; Seymour, 1992; Vogt, Hocevar, & Hagedorn, 2007). For example, studies have shown that students with lower levels of self-efficacy are more likely to become discouraged with the competitive grading structure and isolating nature of engineering courses (Lent et al., 2003; Schaefers et al., 1997).

In summary, existing literature in the field of engineering education highlights the value of collaboration (e.g., Suresh, 2006; Geisinger & Raman, 2013), project-based learning (e.g., Dym et al., 2005; Knight et al., 2007), and connections to engineering as a career (e.g., Busch-Vishniac & Jarosz, 2004; Froyd et al., 2012) for engaging and retaining more students, and especially more diverse students, in engineering. Furthermore, studies have shown that low self-efficacy is highly correlated with attrition in engineering programs (e.g., Leslie et al., 1998; Vogt et al., 2007). However, there is a dearth of research exploring the impact of well-designed engineering curricula on engineering students' self-efficacy beliefs, in particular during the critical freshman year. Our study aims to fill this gap in the literature by analyzing the changing self-efficacy beliefs of a group of 10 freshman engineering students enrolled in a recently redesigned first-year mechanical engineering course.

Theoretical Framework

This study is grounded in the self-efficacy component of Bandura's (1986) social learning theory. According to social learning theory, people learn from observation, imitation, and modeling of others. Self-efficacy reflects the degree to which people believe they can be successful, embodying what they feel they can offer to a larger group. Self-efficacy beliefs influence how much effort people expend to achieve a goal, how long they persevere in the face of obstacles, and how resilient they are in adverse situations—a higher sense of efficacy leads to greater effort, persistence, and resilience (Bandura, 1997). According to Bandura (1997), the construct of self-efficacy differs from that of confidence, in that:

> Confidence is a nonspecific term that refers to strength of belief but does not necessarily specify what the certainty is about. I can be supremely confident that I will fail at an endeavor. Perceived self-efficacy refers to belief in one's agentive capabilities, that one can produce given levels of attainment. A self-efficacy belief, therefore, includes both an affirmation of a capability level and the strength of that belief. Confidence is a catchword rather than a construct embedded in a theoretical system. (p. 383)

The empirical connection between self-efficacy and academic performance has been extensively researched and consistently validated by scholars, particularly in STEM (Science, Technology, Engineering, and Mathematics) fields (e.g., Bores-Rangel, Church, Szendre, & Reeves, 1990; Brown, Lent, & Larkin, 1989; Farmer, Wardrop, Anderson, & Risinger, 1995; Lent, Brown, & Larkin, 1986). For example, research suggests that self-efficacy beliefs influence college undergraduates' academic performance in the fields of mathematics, science, and engineering directly and indirectly through persistence (Lent, Brown, & Larkin, 1986; Schunk, 1984). Self-efficacy is most commonly assessed in the literature using survey items that ask individuals to report on, for example, the strength of their confidence to accomplish a task or succeed in a certain domain, whether they are good in an academic subject, and their understanding of a particular field (Hutchison, Follman, Sumpter, & Bodner, 2006; Pajares, 1996). Along these same lines, the Mathematics Self-Efficacy Scale (MSES) defines math self-efficacy as the composite of individuals' perceptions of their ability to solve math problems, perform math-related tasks, and succeed in math-related courses (Betz & Hackett, 1983).

Bandura (1977) describes self-efficacy as being primarily developed through performance accomplishments. According to Bandura, mastery experiences are especially impactful because they increase individuals' expectations for success; in contrast, failures lower success expectations, particularly if they occur early. As individuals experience repeated successes, they are more self-motivated to persist through obstacles and more resilient in the face of failures. Additionally, as Bandura (1977) explained, self-efficacy is influenced to a lesser degree by vicarious experiences, seeing others achieve success in a given domain; social persuasions, suggestions from others that they can master difficult situations; and physiological states, namely anxiety and stress. The implications of vicarious experiences on self-efficacy are typically most pronounced for underrepresented populations, such as women in engineering fields (Bussey & Bandura, 1999; Hutchison et al., 2006).

In line with Bandura's (1986) emphasis on mastery experiences as the most influential source of self-efficacy, our focal freshman engineering course was designed to support student learning through experiencing firsthand the engineering design process. Our study explores the impact of this freshman engineering course on engineering students' self-efficacy beliefs over a period of 10 weeks.

Research Methods

Context

The focal course, *Introduction to Engineering Graphics, CAD, and Design*, was a required freshman course taught in the department of mechanical engineering at a university in Southern California. The course ran for 10 weeks each spring quarter, with two classes and one lab session each week. The objective of this course was to introduce hands-on engineering design via lessons on the design process, Computer Aided Design (CAD), multiview engineering drawings, free hand sketching, use of a laser cutter, soldering, basic circuits, basic microprocessor programming, motors, and gear trains. This project-based course relied on a robotics project to allow students to practice all aforementioned topics. As part of the project, the engineering students partnered with elementary children from a nearby elementary school, who served as their clients dictating how the robots should look and move. At the end of the quarter, all the robots came together to perform a coordinated dance at a final engineering design fair held at the university.

The undergraduate students in this study worked in teams of four-to-five to design, build, and program their robots. One or two team members interfaced directly with the clients (children) through three design team meetings spread throughout the quarter (Figure 3-1). During the first meeting, the engineering students collaborated with their clients to produce preliminary free hand engineering sketches of their robots; they later shared these sketches with their remaining team members. The second meeting served as an opportunity for the engineering students to inform their clients of their progress with updated multiview engineering drawings of the robots. And during the third meeting, the engineering students presented the CAD drawings to their clients for a final round of feedback before the dance show.

All freshman students who interacted directly with the client at least once throughout the quarter were asked to participate in interviews for this research project. Of the 50 freshman mechanical engineering students (see details in Table 3-1) enrolled in the course, 19 met this criteria and 10 agreed to be interviewed. These 10 students served as the focal group for our study.

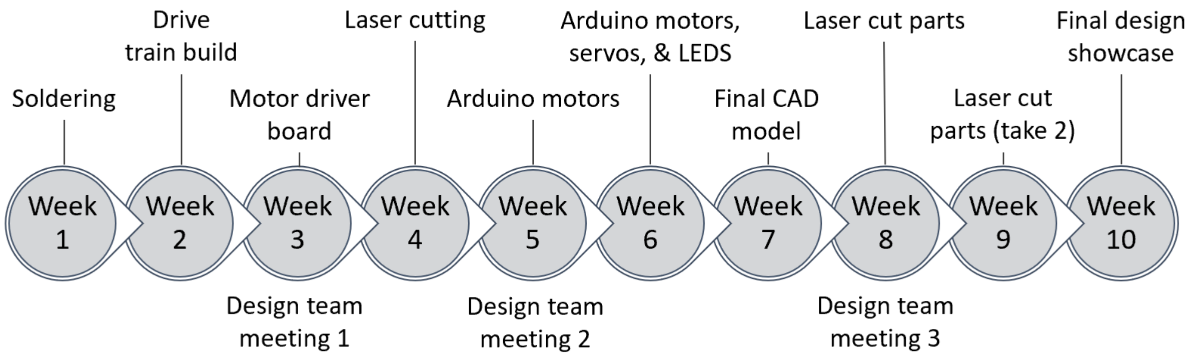

Figure 3-1. Timeline of lab topics and design team meetings throughout the 10-week quarter.

Table 3-1

Student Overview

Students by Group	Total in Course	Percentage in Course	Interviewed
Gender			
Female	10	15%	2
Male	58	85%	8
Total	68		10
Ethnicity			
White or Asian	51	75%	7
Underrepresented minority	17	15%	3
Total	68		10
Year in program			
Freshman	50	74%	10
Sophomore or higher	18	16%	0
Total	68		10

Note. There were a total of 77 students enrolled in the focal course; however, only 68 consented to sharing their demographic data. The demographic make-up of this course is fairly representative of the field of engineering as a whole: Of the engineering undergraduate degrees awarded in the US, approximately 80% go to men and 71% to White or Asian students (NSF, 2015).

Data Collection

The initial interviews for this study were conducted during Weeks 1 and 2, prior to the first engineer-client meeting and the final interviews took place during Week 10, the last week of the quarter. The first round of interviews were designed to assess students' engineering self-efficacy prior to their experiences in the focal course and the final round of interviews explored the manner in which the students' engineering self-efficacy changed over the quarter. The final interviews also probed the role of the focal course on students' changing self-efficacies related to engineering. The guiding interview questions used for this analysis are shown in Table 3-2. The interviews were audio recorded for analysis.

Table 3-2

Guiding Questions for Pre- and Post-Quarter Interviews

Pre-quarter guiding questions:

1. How did you come to volunteer to work directly with the clients?
2. How would you describe an engineer?
3. How do you feel about doing engineering projects?
4. To what degree do you identify as an engineer?
5. How good at engineering are you?
6. How do you think you compare to your peers in engineering?
7. How well do you expect to do in this engineering course?
8. How good would you be at learning something new in engineering?
9. What does being a role model mean to you?

Post-quarter guiding questions:

1. How did you feel about your experience working directly with the clients?
2. How do you think they perceived you?
3. Thinking about the elementary students in their role as your clients, to what degree did they feel like real clients?
4. How did this relationship to design and build for a client impact your experience with the course?
5. What did you think about the goal of this project—to have the robots dance together instead of having a competition for the robots to compete in?
6. To what degree do you identify as an engineer?
7. How good at engineering are you?
8. How well do you feel you did in this course?
9. In general, how would you describe your experience with this course?
10. What did you learn from your experiences in this course?
11. How did your experience in this course compare to your other courses?

Analysis

The data analysis was qualitative in nature and relied on pre- and post-quarter interview data collected from 10 undergraduate engineering students. To begin, the interview data were transcribed for analysis, all names were replaced with pseudonyms, and the transcripts were checked against the original recordings for accuracy. Next, a research team consisting of three of the authors on this paper assembled to develop a coding scheme for the interview data using both a priori codes from the self-efficacy literature (e.g., confidence in current ability, expectations for success) and emergent codes that became relevant during data analysis (e.g., believability as a client, real world experience). The final coding scheme is shown in Table 3-3. To ensure trustworthiness of the data analysis, we collectively coded all of the interviews. After defining the codes as a research group, each researcher individually coded the data, then met together to discuss the assigned codes, and resolved all disagreements through discussion; the final coding reflected consensus.

To answer our research question related to students' changing engineering self-efficacy, we compared responses in the pre- and post-quarter interviews. We investigated the impact of the engineer-client relationship on the undergraduates' engineering self-efficacy, and analyzed comparisons between students' experiences in the focal engineering courses and other required courses for their majors.

Table 3-3

Codes Used for Qualitative Analyses of Interview Data

Topic	**Codes**	**Definition**
Engineering self-efficacy	Confidence in current engineering ability a. Self evaluation b. Comparison to peers	Students describe that they currently (a) have some degree of confidence in their existing engineering skills or knowledge, or (b) compare their engineering competence to that of their engineering peers.
	Growth mindset	Students describe beliefs in their ability to learn new material or acquire new skills in engineering through effort and persistence.
	Thinking of oneself as an engineer	Students explain that they currently consider themselves engineers in some respect.
	Being thought of by others as an engineer (social persuasions)	Students explain that others view them as engineers or believe they are capable in engineering.
	Expectations of success for future engineering endeavors	Students explain that they expect to be successful in their engineering program, related engineering tasks, or engineering career.
	Anxiety/stress	Students describe anxiety or stress deriving from their experiences in engineering.
	Influence from role models (vicarious experiences)	Students describe engineer role models who have inspired them to work hard and continue in the field of engineering.
Engineer-client relationship	Believability as a client	Students describe their view of the elementary students in the role of engineering clients.
	Real world experience	Students describe the experience of working with a client on this project as a "real world" experience.

	Collaboration	Students discuss one or more of the collaborative aspects of this program, including: working as part of a team, working with clients, working towards the shared goal of a coordinated robot dance performance.
	Serving as a role model a. Feeling good about inspiring the next generation of engineers b. Leading by example c. Identifying with/seeing themselves in the elementary students d. Learning by teaching	Students describe that in working with the elementary students they (a) feel good about inspiring them to become engineers, (b) feel as though they are leading by example, (c) identify with the elementary students in some respect, or (d) learn by teaching engineering.
Program rigor	Mastery experiences	Students describe the successful completion of engineering projects or tasks in the focal course.
	Learning outcomes	Students describe what they learned from their experiences in the focal course.
	Preparation for future in engineering	Students explain that their experiences in the focal course made them feel more prepared for their futures in the field of engineering.
	Comparison to other courses in engineering major	Students compare their experiences in the focal course to other courses required for their engineering majors.

Findings

To answer our research question—What impact did this course have on the freshman engineering students' engineering self-efficacy beliefs?—we analyzed the manner in which 10 freshman students responded to a series of pre- and post-quarter interview questions. Through this analysis we found that all students reported increased engineering self-efficacy beliefs by the end of the quarter and attributed a large part of their increased self-efficacy to the focal engineering course. We further identified two key sets of findings. First, the project-based nature of this course, which scaffolded learning of the skills necessary to complete the final project, contributed to students' increased levels of engineering self-efficacy while maintaining a high level of rigor, as expected in the engineering department. And second, elementary children serve as effective clients for engineering students in first-year courses because they are more accessible than industry clients, they provide a low-stress learning opportunity, they view the freshman engineering students as real engineers, and they benefit from the experience, too.

Project-Based Learning

The well-executed PBL nature of this course was found to be successful in helping students feel more competent and confident in their engineering abilities. Importantly, the course scaffolded the learning of skills necessary to complete the final project through weekly hands-on lab sections. From soldering to CAD to laser cutting, students gained mastery experiences in supervised lab sections where they were comfortable asking for help before they ventured out on their own. This scaffolded learning strategy appeared especially important for the freshman students, as most entered their programs with limited prior experiences in engineering. For example, in his pre-quarter interview, Anthony discussed his worries around entering the program with less experience than some of his peers.

> I mean I think that I can [do well in this program] and that I will earn my place, I guess, I don't know. I mean, in relative status, I feel a little bit less experienced than a lot of these guys because, like I said, a lot of them I think have engineering parents. And I've talked to a lot of them, a lot of them *do* have engineering parents. And a lot

of them have been in a robotics club or have had internships, I guess, you know. And I really haven't had that. So I feel like a little bit lower on the totem pole, but it's, I think that I can get there and if I put in the work then eventually I'll be on the same level.

By the end of the quarter, in contrast, Anthony felt much more comfortable, competent, and engaged in engineering; he felt more like an engineer.

> I feel a little more engineery…. I definitely do feel more confident in my engineering abilities. I know how to use a laser cutter now. I know what a servo is, I didn't know what a servo was before. And from start to finish I guess now I know the whole engineering process per se. So yeah, I feel more comfortable…. I really liked the course. Kinda going into it, I was thinking, if I liked this then I'd stick with it. If I didn't, then I'd switch out. But it's been my favorite class by far. So I think I'll stick with it…. As for changing my perspective, I've sent a couple of snapchat videos of our robot to my friends cause I've told them I've been working on the project and they want to see it. And then they all say, "Oh, that looks really tough, really complicated." And it's really not, in hindsight. They, one friend in particular, said they could never imagine building a robot. No, I think you could, you know. I don't feel significantly smarter than the average student. I just, I took the class and I worked for it, so I think anyone could, at least at this point of education, anyone could make a robot.

Anthony attributed his growth as an engineer in large part to his experiences in the focal engineering course. Not only did he acquire new skills, his self-efficacy beliefs in engineering substantially increased. Mastery experiences in this class translated into increased confidence in his abilities and excitement for his project. The awe that Anthony's friends expressed over his dancing robot also contributed to his increased self-efficacy beliefs through the power of social persuasions, as described by Bandura (1977). We also witnessed, through Anthony's interviews, how impactful first-year engineering courses are on students' decisions to persist in the field. Anthony explained that if he did not like this course, one of the first engineering courses he encountered in his major, he was planning to switch to another program.

The sentiments expressed by Anthony were echoed by most of the other students interviewed from the course. For example, Cameron compared his experience in this mechanical engineering course to another engineering course he had completed in the electrical engineering department the previous quarter and explained how he benefited from scaffolded, hands-on instruction.

> So far I took ECE 5, which is like the projects class for electrical engineers. And in that class, we only had four weeks of lecture and then we were dropped into our projects for that class. It was a lot more open-ended. We weren't making dancing robots; we could make anything we wanted. And I felt like this one [the focal course] was a better intro class, because it explained all the steps along the way, and it really just, it was good. We had enough freedom to make what we wanted, but not enough freedom to where it's overwhelming.

While the focal engineering course helped to increase students' engineering self-efficacy beliefs, we emphasize that this was *not* achieved at the expense of rigor. This course did not boost students' confidence by presenting them with easy projects; the projects were difficult and time-consuming and pushed the students to work hard and step outside of their comfort zones. For this analysis, we defined a *rigorous* course as one that results in substantial learning. Using this definition, all engineering courses should be rigorous because the profession of engineering demands competent and knowledgeable individuals. Interviews with students suggest that all 10 students learned more in this course than in any of their other freshman courses. For example, according to Carly,

> I feel like I learned a lot more [than in other courses] just because I was interested in what was going on, and you can't just search it up online. For all the other classes, it's basically doing just busywork, and just like studying for exams. But this one, you had to know what was going on.

Similarly, Tarak explained,

> This class is actually learning I would say compared to [other courses]. We're taking chemistry and I'm just memorizing stuff that I won't use a ton of later on but this is the stuff that is pretty much the basis of our major. So, I just thought it was really helpful to get that experience now and work on it pretty much forever.

In sum, this rigorous course helped to both increase students' self-efficacy beliefs and maximize learning through inclusive instructional pedagogy.

Elementary Children as Clients

As mentioned above, each team of engineering students was partnered with a group of two-to-four fifth- or sixth-grade children at a nearby public elementary school. The elementary children served as the clients for the engineering students; they dictated what the robots should look like, how they should dance, and they were required to approve all stages of the design, including the initial sketches, the more-detailed engineering drawings, and the final CAD designs. We found that having a client modeled the real world experience of being a professional engineer and helped the engineering students view themselves more like real engineers. For the most part, the engineering students thought that the elementary school students were similar to industry clients, even though they were children. For example, Christian explained,

> I mean yeah, they did a lot of what customers usually do. They told us what they wanted. Like, "Hey, let's do this. I want this, this, and this." And we'd go back to them, like, "Hey, we have this and this idea. Which one do you like best?" They would pick one, and then we built it. I think it was definitely a good experience. We do need practice designing for customers because that is mainly what we will be doing when we get out of here. So definitely a good experience.

Similarly, Huang commented,

> I think, although they are not serious customers. I don't mean it that way. But they are just, they can still be able to provide some useful advices and I would imagine that is, if I, in the future, meet like an adult, a real customer, it probably would be the same thing. [The adult clients] are just more, their advice or their thoughts are more probably reasonable or they will provide some reasoning behind their advices and all

> that. In general, I think it gives me the first impression of how a customer meeting would be. Kind of like, our project is, it is like a process. We take them advice and improve constantly in order to get to the ultimate goal.

The fact that the elementary children were not exactly the same as industry clients was actually beneficial to our goal of fostering self-efficacy beliefs in the freshman students. As Huang alluded to, designing for children was a test run for designing for adults and as a result, the experience was less stressful.

Beyond serving the role of client, the elementary children were overjoyed to work with the engineering students and saw the freshmen as professional engineers. This contributed to a good experience for both the elementary children and the engineering students. According to Christian,

> You know, I thought it [working with the children] was pretty cool…especially the first meeting when we brought the LEDs. Like, "Hey, look at this, this spark, this spark. You put your batteries in the middle, it lights up." They are like, "Oh my god, oh my god, look at this. Look at what our engineers brought us!" So that was pretty cool.

And Cameron noted, "I think they thought of us as pretty good engineers." Being viewed by others, even children, as professionals can help foster self-efficacy beliefs through social persuasions.

Discussion

Over the last decade or so, there have been persistent calls to redesign engineering education to improve retention and diversity in engineering (Baker, Krause, Yaşar, Roberts,

& Robinson-Kurpius, 2007; Busch-Vishniac & Jarosz, 2004). According to Geisinger and Raman (2013),

> A significant proportion of engineering students leave because the engineering educational system has failed to show them that the engineering endeavor is profoundly human, has failed to make relevant the key scientific, mathematical, and engineering principles needed for mastery of engineering, has failed to show that engineering is within reach of their abilities, has failed to capture their imagination and fascination, and has failed to provide a welcoming atmosphere to them. (p. 920)

While a large body of research suggests that low self-efficacy is a main driver of attrition in engineering programs (e.g., Leslie et al., 1998; Vogt et al., 2007), there is a paucity of work examining the relationship between well-designed engineering courses and self-efficacy beliefs. Our study aimed to fill this gap in the literature by providing a detailed analysis of 10 freshman engineering students experiences in a redesigned first-year mechanical engineering course. Through pre- and post- interviews, we analyzed the impact of the supportive project-based focal course, which incorporated client-led design with elementary children as clients, on students changing self-efficacy beliefs.

We found that all 10 students identified the focal course as responsible, in large part, for their increased levels of confidence in their engineering abilities and growing self-efficacy beliefs. The supportive nature of the course, executed through regular weekly scaffolding of foundational engineering skills, proved important for helping students feel like competent engineers. The students' early experiences mastering the entire engineering design process provided them with the knowledge and confidence they needed to design and build complex dancing robots to the specifications set forth by their clients. The scaffolded hands-on component of this course supported students in successfully completing their final projects without sacrificing the level of rigor expected of any undergraduate engineering course. Most students reported learning more in this course than as in any of their other courses to date.

The freshman students in our study also benefited from the authentic experience of designing their final projects to meet the needs of clients. Professional engineers "generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (Dym et al., 2005, p. 104). Furthermore, the fact that their clients were elementary children and not industry professional actually proved beneficial for achieving our goal of increasing the freshman students' self-efficacy beliefs. Designing for child clients felt legitimate—they had to fulfill the children's requests—but less stressful to the freshman students, almost like a test run for designing for adults. According to Bandura (1977), anxiety and stress can reduce self-efficacy beliefs so it is important to scaffold experiences as well as skills in engineering. Additionally, the children viewed the freshman students as real engineers, further promoting self-efficacy beliefs through social persuasions.

The results from our study suggest that supportive project-based engineering courses, designed with clear connections to engineering as a career, foster self-efficacy beliefs in undergraduate students. These courses are especially valuable during the critical freshman year, when we see the highest rates of attrition in most undergraduate programs, often as the result of negative experiences in gatekeeper courses (Knight, Carlson, & Sullivan, 2007; Moller-Wong & Eide, 1997). Further, partnering with elementary schools as a way to incorporate client-led design in first-year courses is highly effective, mutually beneficial for the freshman and elementary students, and accessible; industry clients are typically more interested in working with senior students who have more experience and are preparing to enter the job market.

Conclusions

In this study, we analyzed the impact of a redesigned freshman mechanical engineering course on students' engineering self-efficacy beliefs through pre- and post-quarter interviews with 10 freshman students. The focal engineering course was designed to support student learning through scaffolded mastery experiences in a highly relevant project-based environment, whereby the students designed and built robots to meet the needs of clients. We found that this course played a substantial role in increasing all 10 freshman students' engineering self-efficacy beliefs over the course of the quarter. In particular, the scaffolded hands-on projects and experiences designing for clients helped the freshman students, who were novices in the field of engineering, gain the mastery experiences necessary to feel competent and capable as engineers. Moreover, working with elementary children as clients, proved ultimately beneficial because it felt similar to working as a professional engineer but with less pressure and the benefit of having clients who looked up to you and truly viewed you as an engineer.

This study was limited in that we only interviewed freshman students who worked directly with the elementary children throughout the quarter; they reported back to their teammates, who were unable to make it to the meetings. While we expect that, at the very least, the remaining students would have comparable experiences with the scaffolded PBL nature of the course, and also benefit from designing within the constraints of the client in some respect, we are interested in exploring a more representative population in future studies.

Nonetheless, the specific design of this course has direct implications for the field of engineering education and could easily be adapted for other STEM (Science, Technology, Engineering, and Mathematics) fields, especially those that suffer from comparably high rates of attrition. The findings from this study support the notion that designing courses to support student learning through scaffolded and relevant hands-on projects helps to increase students' self-efficacy beliefs, which have been shown to be highly correlated with retention. Furthermore, client-led design appears an effective way to make courses relevant to engineering as a career. Elementary children are ideal clients because they simulate the real client experience in a lower pressure environment and they view the freshmen as real engineers, which promotes self-efficacy beliefs through reduced anxiety and stress, as well as through social persuasions. Additional strengths include that elementary children are more accessible as clients than industry for freshman level courses (industry typically partners with experienced seniors ready to join the job market) and that the children themselves benefit from this experience as well; everyone wins.

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Chapter 4: *The importance of community for narrowing the gender gap in engineering: An analysis of engineering identity development in elementary students.*

Abstract

Research suggests that, to narrow the gender gap in engineering, we should focus on helping young girls identify with engineering both because gendered attitudes emerge around kindergarten and because identity is more predictive than performance on persistence in the field. This qualitative study sought to understand the impact of an engineering community on the development of engineering identities in elementary school students and compared the findings across gender. We focused on three tiers of collaboration within this community: peer groups, role models, and shared goals. More specifically, the elementary students worked in small teams and partnered with undergraduate engineers to help design and build dancing robots that came together for a coordinated dance performance. We used ethnographic methods, including pre-post student interviews, video-recorded program sessions, and documentation of student work, to investigate elementary students' engineering identities. Three themes emerged from our analysis. First, working with peers encouraged students who were initially uninterested in engineering, the majority of whom were girls, to join the program and helped them to engage in the activities. Second, partnering with engineer role models contributed to the elementary students' developing identities as engineers: The girls were most influenced by the personal bonds they formed, while the boys were most influenced by the technical skills they learned. Third, all girls and most boys preferred the idea of working towards a shared goal to competitive projects that,

as described by the students, can cause bad feelings and hurt friendships. Our work supports and extends elementary engineering literature by considering the role of multiple tiers of collaboration on identity development in girls and boys. Our results suggest that engineering communities that foster collaboration can help more students, especially more girls, engage in and identify with engineering, thereby contributing to the narrowing of the gender gap.
Keywords collaboration; elementary school; engineering identity; gender gap; role models; shared goals

Introduction

Over the last few decades, the gender gap in STEM (Science, Technology, Engineering, and Mathematics) achievement has narrowed considerably. From elementary school through high school, girls and boys are now completing approximately equal numbers of mathematics and science credits and girls are earning slightly higher grades (Hill, Corbett, & St. Rose, 2010; Régner, Steele, Ambady, Thinus-Blanc, & Huguet, 2014). A gender achievement gap, however, remains in advanced high school STEM courses—fewer girls take advanced placement science and mathematics—a trend which continues into college and the workforce. And girls still comprise a smaller percentage than boys of the highest achieving students in mathematics based on the SAT, although the ratio of high achieving boys to girls has decreased from 13:1 in the 1980s to 3:1 in the early 2000s. Furthermore, women receive only 20% of engineering undergraduate degrees in the US and comprise only 15% of the engineering workforce (NSF, 2015). The research reported here focuses on engineering, one of the most homogeneous of all STEM domains.

Although efforts have been made to address this persistent gender gap in engineering, research makes clear that targeting students at the college level to increase diversity in engineering is not sufficient. Gendered attitudes towards mathematics are evident by kindergarten (Ceci, Ginther, Kahn, & Williams, 2014). By age six, both girls and boys are significantly more likely to classify males as “really, really smart”—a trait commonly attributed to engineers—and fewer girls show interest in games for “really, really smart” children (Bian, Leslie, & Cimpian, 2017). In addition, after controlling for actual mathematics ability, high school students with higher self-assessments of mathematics ability (who tend to be males) are more likely to enroll in high school calculus courses and subsequently major in STEM fields in college (Correll, 2001). These findings suggest that measures of domain-specific *identity* may have a greater impact on career choices than does performance. As such, understanding how engineering identities are constructed is vital for diversifying the field. The extent to which students engage in engineering in classrooms depends upon whether they view themselves as the type of people who can become engineers, i.e., whether or not they *identify with the domain* (Brickhouse, Lowery, & Schultz, 2000). And whether or not students develop identities in domains such as engineering has been shown to substantially impact their future educational and career choices (Vossoughi & Bevan, 2014).

Our research attempts to contribute to narrowing the gender gap in engineering by investigating a partnership between elementary students and undergraduate engineering students. The partnership was designed to shift the focus from helping diverse groups *fit* into the current engineering culture toward changing the culture to better reflect a broader range of views and experiences by emphasizing the social side of engineering (Bianchini, Cavazos, & Helms, 2000; Calabrese Barton & Brickhouse, 2006). More concretely, we explored the role of *community* in the formation of elementary students’ engineering identities. The partnership program facilitated the building of community through three tiers of collaboration. First, the elementary students worked together in small peer groups. Second, each elementary student group partnered with engineering undergraduate students to design and build dancing robots. Third, elementary students and undergraduate engineers brought all of the robots together to perform a coordinated dance. In other words, we investigated how elementary students' engineering identities were influenced by the engineering community of practice, which was defined on three levels: working with their peers, working with undergraduate engineering role models, and working on projects towards a shared goal (the final robot dance). We used data collected from elementary student participants over a period of 10 weeks to answer the following two research questions: (1) How did the degree to which the elementary students identify with engineering change over the course of the program? (2) What role did the engineering community of practice play in the development of their engineering identities? We analyzed these data first as a collective and then again by gender.

Situating Our Study in the Literature

We found no studies to date that have investigated the role of community—defined as more than peer groups—in constructing identities to narrow the gender gap in engineering at the elementary school level. Much of the related research has focused on science in middle and high school, as opposed to engineering in elementary school. And many of these studies have not considered differences across gender. In an effort to fill these gaps in the literature, our study extends previous research related to role models and collaboration in K-12 STEM community-based programs.

Research on role models suggests that “modeling is one of the most pervasive and powerful means of transmitting values, attitudes, and patterns of thought and behavior” (Bussey & Bandura, 1999, p. 686). In particular, seeing someone achieve a valued outcome through effort has been shown to instill motivating expectancies for similar outcomes in others, if they put in comparable work. Our study builds on research related to how middle school girls identified with science role models. In a qualitative study with 13 eighth-grade girls, for example, researchers found that scientists’ personalities and abilities to make personal connections with the girls were more important to their success as role models than their expertise in science (Buck, Clark, Leslie-Pelecky, Lu, & Cerda-Lizarraga, 2008). In fact, the girls in this study explained that they were less likely to view scientists who were “too good” or “too smart” as role models because they were unable to relate to them. These results resonate with Lockwood and Kunda’s (1997) research on role models, which suggests that seemingly unattainable success can be self-deflating instead of inspiring.

The perception of engineering as highly competitive has been found to discourage participation by students who are underrepresented in the field and are subsequently primed to be impacted by negative stereotypes, such as the stereotype that girls and women are less capable in quantitative fields (Busch-Vishniac & Jarosz, 2004; Goodman et al., 2002; Shapiro & Williams, 2012). In response, a large body of research has shown that collaboration can be used to engage a more diverse population in engineering and help individuals construct engineering identities (Busch-Vishniac & Jarosz, 2004; Cunningham & Lachapelle, 2014; Goodman et al., 2002; Menekse, Higashi, Schunn, & Baehr, 2017; Pattison, Gontan, Ramos-Montañez, & Moreno, 2018). Teamwork provides students with opportunities to contribute in a variety of ways, thereby placing value on diversity rather than creating hierarchies with competition. However, most engineering programs *only* consider the element of teamwork and continue to center project goals around competitions, such as building the strongest bridge, the tallest tower, or the fastest robot. For example, robotics competitions are becoming increasingly popular in K-12 educational programs, with over 230,000 students participating in approximately 29,000 FIRST (For Inspiration and Recognition of Science and Technology) Lego League robotics teams across 80 countries in 2015 (Menekse et al., 2017). A study conducted with 366 K-8 students involved in a FIRST Lego League found that more collaborative teams produced better robots, yet the authors did not acknowledge the fact that the league was highly competitive in that only the best robots were recognized as winners. Similarly, other studies have explored the role of collaboration in informal engineering environments on students' engineering identities without considering the value of shared goals (Wang, 2013).

In sum, more research is needed to understand how engineering communities can be enacted to help more students, especially more girls, at the elementary level identify with engineering. Our study extends the existing literature on STEM communities by providing insight into how role models and shared community goals—in addition to peer groups—influence elementary girls' and boys' identities as engineers.

Theoretical Framework

Our study, grounded in feminism as a movement towards social justice, explores the potential of engineering communities of practice to help more girls develop identities as engineers by placing value on the social nature of engineering. Prominent feminist scholars such as Fox Keller (1987), Haraway (1988), and Harding (1996) have demonstrated through their work that scientific knowledge is culturally situated (i.e., bound by sociocultural contexts) and inherently gendered. According to Brickhouse (2001), science traditionally promotes and operates within a number of dualisms, including the male/female dualism:

> This feminist critique of Enlightenment epistemology describes how the Enlightenment gave rise to dualisms (e.g., masculine/feminine, culture/nature, objectivity/subjectivity, reason/emotion, mind/body), which are related to the male/female dualism (Hekman, 1990), in which the former (e.g., masculine) is valued over the latter (e.g., feminine). (p. 283)

Another dualism—technical/social—is discussed in feminist research on engineering education. By deemphasizing social skills and overvaluing technical skills as the only *real* or pure engineering practice, US engineering programs currently foster a culture of disengagement with public welfare concerns (Aschbacher, Tsai, & Others, 2014; Cech, 2013; Faulkner, 2007). Faulkner (2007) elaborated, " Promoting an image of engineers and engineering as both technical and social should have an impact on the retention and career progression of women engineers as well as on their recruitment" (p. 352).

Research on women in engineering has found that women often adopt masculine interaction styles in order to fit in with their mostly male colleagues (Hatmaker, 2013; Jorgenson, 2002; Tonso, 2006). This message that women must ignore or change aspects of their identities to succeed in male-dominated environments fuels the homogeneity of engineering. Similar issues abound in the K-12 STEM educational system whereby girls are commonly viewed through a deficit lens and taught how to learn engineering in the same manner as boys. Feminism as a movement toward social justice takes an inclusive perspective on education and shifts the focus from helping girls (and other diverse groups) adapt to the current engineering culture toward changing the culture to better reflect a broader range of views and experiences (Bianchini et al., 2000; Calabrese Barton & Brickhouse, 2006). In particular, developing programs that value the social nature of engineering can help overturn the current view of engineering as purely technical (Hynes & Swenson, 2013). While technical skills are certainly essential for any engineer to be successful, working as part of a team towards a shared goal is also important and deserves recognition and value.

The goal of our partnership program was to help more students, in particular more girls, develop identities as engineers by placing value on the social side of engineering. We attempted to accomplish this goal through the development of a collaborative engineering community of practice (Lave, 1991). The community of practice in our study comprised the elementary students and the undergraduate engineers who came together regularly to share knowledge and experiences related to engineering. This community was collaborative not only because elementary students worked with role models in teams but because students worked toward a shared goal of a final coordinated robot dance performance.

Identities develop as students engage in communities of practice (Lave, 1991; Tan & Calabrese Barton, 2008; Tan, Calabrese Barton, Kang, & O'Neill, 2013; Tonso, 2006). As summarized by Lave (1991), "[T]he fashioning of identity is the means through which members become full participants" (p. 72). Our analysis is based on a *situated perspective of identity* (Gee, 2000), which considers how identities are context-dependent and negotiated with oneself and between oneself and others. In line with research on measures of situated science and engineering identity, in this study, we defined engineering identity as consisting of two dimensions: thinking of oneself as an engineer and being thought of by others as an engineer (Calabrese Barton et al., 2013; Pattison et al., 2018; Tonso, 2006).

We end this section with two important clarifications for our endeavor to help narrow the gender gap in engineering. First, we acknowledge that individual behaviors do not fall along a gender binary and that there is much heterogeneity within each gender. Still, for the purposes of this research, we relied on the gender binary as an analytic tool while recognizing its limitations. Second, research focused on community building in engineering details culturally responsive practices that have also been shown to engage traditionally underrepresented racial and ethnic groups (Scott & White, 2013). Since our research study was carried out at a school in Southern California with a predominantly Latinx population, our reach extends beyond gender, although the comparative portion of our analysis for this paper is focused on gender.

Research Methods

Context

The context for this research study was a partnership program between an elementary school and a university in Southern California. The elementary school comprised a diverse population of students with respect to race and ethnicity. Approximately one-half of students were Latinx; one-quarter, European American; one-eighth, Asian American; and the remainder, African American, American Indian/Alaska Native, Filipino, Pacific Islander, and mixed race. In terms of socioeconomic status, over half of the students were eligible for free or reduced-price lunch. Furthermore, nearly one-half of students were classified as English language learners.

The after-school program, entitled *Engineering Arts*, was open to all interested fifth- and sixth-grade students for one hour every Friday afternoon for a period of 10 weeks. The elementary students, referred to in the program as *junior engineers*, partnered with engineering students enrolled in a freshman mechanical engineering design course at the nearby university (*freshman engineers*) and volunteers from the university chapter of the Society of Women Engineers (*SWE engineers*); collectively the freshman and SWE engineers are referred to as *undergraduate engineers* throughout this paper. Given that the freshman mechanical engineering course was comprised approximately of 85% men, the inclusion of the SWE engineers helped create a more balanced ratio of men and women engineer role models. To further highlight the diversity of the undergraduate engineers, over the course of the program, nine of the engineer role models presented on how engineering connected to their identities as individuals beyond the classroom and workplace. As examples, Mahalia discussed how her love of music related to her passion for engineering, Adam explained how his knowledge of engineering made him a better volleyball player, and Andrea described how her identity as a rock climber aligned with her identity as an engineer.

Together, the junior engineers and undergraduate engineer role models were tasked to design and build dancing robots. The goal of the project was to create a robot flash mob. By vote, the elementary students decided that the robots would come together and dance to "Wake Me Up Before You Go-Go" by Wham!. Each team consisted of two-to-four junior engineers, three-to-five freshman engineers, and one-to-two SWE engineers. The junior engineers were assigned two tasks to work on that contributed to the final product. First, the junior engineers produced preliminary sketches for how the robots would look and dance, and worked with their freshman engineer partners to iterate on these designs. Second, using traditional circuit supplies, electronic-textile (e-textile) circuit supplies, and/or TinkerCAD with a 3D printer, the junior engineers designed and built one piece of the robot with help from their SWE engineer partners, for example, the 3D-printed head of a unicorn robot or the light-up plush body (sewn with e-textiles) for a whale robot. The freshman engineers were responsible for creating the remainder of the robot for credit in their university course. The SWE engineers volunteered their time to help the junior engineers build their pieces of the robots but were not enrolled in any courses affiliated with this program.

The junior engineers met with their freshman engineer partners for three design team meetings spread throughout the quarter to discuss and revise the engineering designs for the dancing robots and to integrate their pieces for the final product. The second design team meeting took place on the university campus and included a tour of the mechanical engineering labs while the first and last meetings occurred at the elementary school. The teams also met a fourth time, during Week 10 of the program, for the final robot dance performance. During the interim weeks, the junior engineers worked on their contribution to the robot (e.g., the head of a unicorn robot or the body of a whale robot) at the elementary school. This elementary school portion of the program was led by women engineering students from the university chapter of SWE, with help from the lead author of this paper, an engineer and educational researcher. The undergraduate course was taught by a professor of mechanical engineering, also an author on this paper. Figure 4-1 presents an overview of the program and Figure 4-2 illustrates the relationships among the junior engineers, freshman engineers, and SWE engineers.

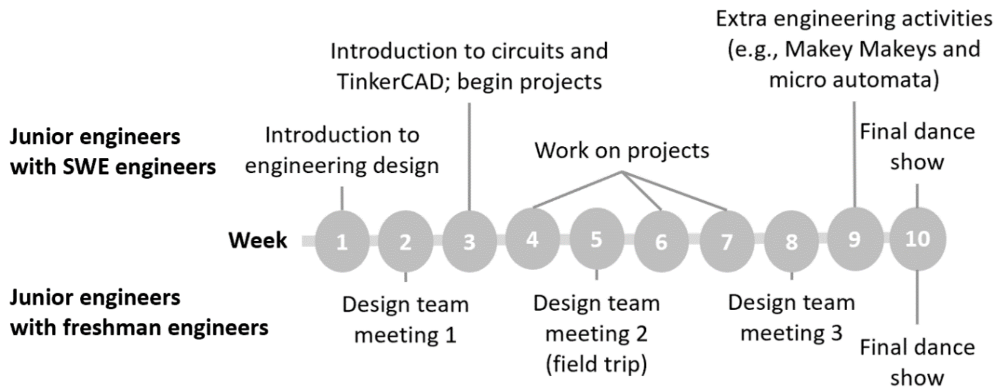

Figure 4-1. Timeline of the 10-week Engineering Arts program.

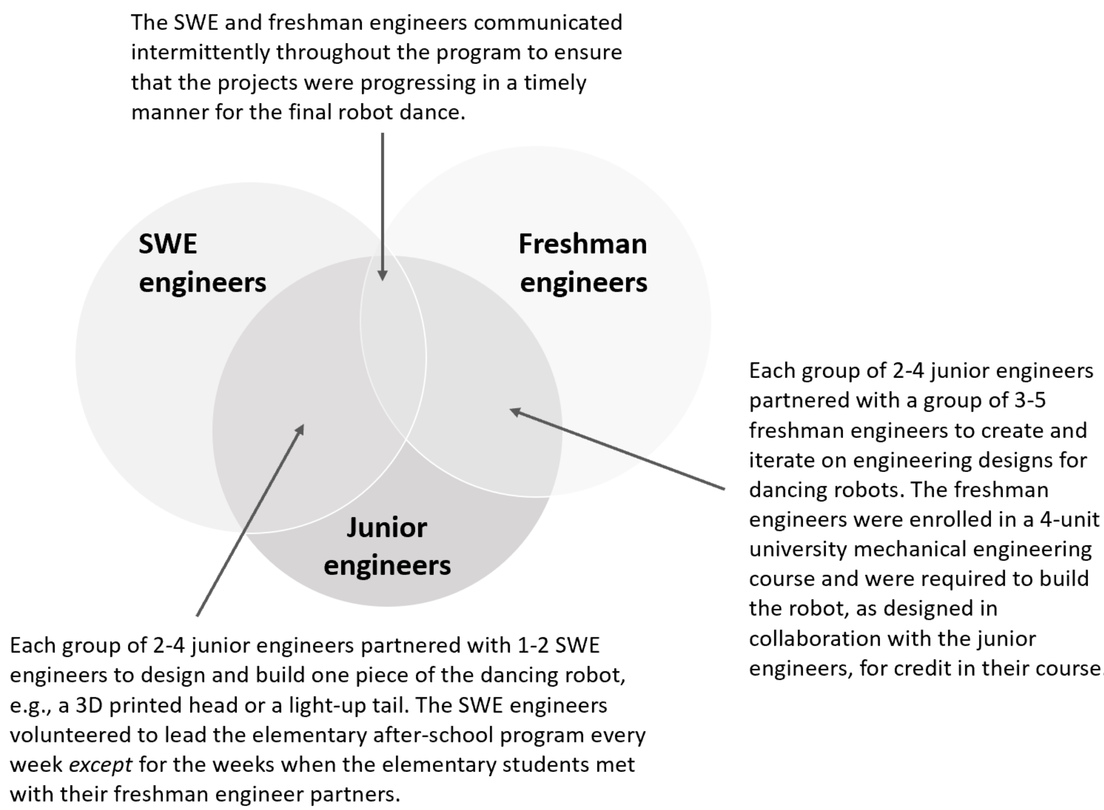

Figure 4-2. Overview of relationships among the junior engineers, freshman engineers, and SWE engineers.

Participants

For this study, we focused on 14 of the 42 fifth- and sixth-grade students enrolled in the after-school engineering program. The group comprised students of all major races and ethnicities enrolled at the school: Latinx, European American, Asian American, and African American. Nearly half were female (6 of 14) and all were in fifth grade. The following criteria were applied to select our sample: (1) Both the student and parents/guardians consented to research, (2) the student did not participate in the pilot study of this program conducted one year prior (which excluded most of the sixth-grade students), and (3) the students completed both the pre- and post-program interviews. The students were divided into groups of two-to-four by a teacher at the elementary school prior to the start of the program; focal students were not necessarily partnered together.

Data Collection

Data were collected for this study over a period of 10 weeks in the Spring quarter of 2018. The full data set includes pre- and post-program interviews with the elementary students, videos of student-to-student and student-to-role model interactions, and a collection of student work.

The pre-program interviews were conducted two-to-three weeks prior to the first session. The post-program interviews were completed during week 10. All interviews took place at the elementary school and were carried out by the lead author of this paper—a former teacher with many years of experience working with and researching children. Interviewing is a valuable investigative tool because it offers detailed insight into people's thoughts, ideas, and opinions (Buck, Clark, Leslie-Pelecky, Lu, & Cerda-Lizarraga, 2008). With the goals of the paper in mind, semi-structured interviews were conducted to ensure that we would be able to answer our research questions while still giving the participants a voice. The guiding questions for the pre- and post-program interviews used for this analysis are shown in Table 4-1.

Table 4-1

Guiding Questions for Pre- and Post-Program Interviews

Pre-program guiding questions:

1. Why did you sign up for this program and what do you hope to get out of it?
2. Do you know any engineers?
3. How would you describe an engineer?
4. How important is it to you to be good at engineering?
5. Do you think that you are an engineer?
6. How good do you feel you are at engineering?
7. Do you think you might work as an engineer one day?
8. What makes a person your role model?
9. What are some things we should look for in the engineer role models you will work with in this program? What should we be careful to avoid?

Post-program guiding questions:

1. How would you describe your experience with this program? Probe: What did you like most? Least?
2. What did you learn from your experiences in this program?
3. How did you feel about working with the undergraduate engineers (insert names)?
4. Would you consider them (insert names) to be role models for you? Why?
5. How did you feel about having the robots dance together, rather than competing?
6. How important is it to you to be good at engineering?
7. Do you think that you are an engineer?
8. How good do you feel you are at engineering?
9. Do you think you might work as an engineer one day?
10. What makes a person your role model?
11. Do you have any feedback about how to make this program better?

Video data was collected for two groups during eight of the 10 weekly sessions. These two groups, containing four of the 14 focus students, were selected because they were the only groups in which all participating students and parents/guardians consented to be video recorded. Weeks 1 and 9 were not recorded because the students worked collectively as a club, thus, we were unable to track our two focal groups. The video data from the program provided us with a deeper understanding of the engineering community of practice, as it was enacted in this program. For this analysis, we focused on two video records: the first design team meeting with the freshman engineers and the first project session with the SWE engineers. We explored how the elementary students interacted with one another and their undergraduate engineering partners, as well as the manner in which they discussed the project. We chose to analyze the first design team meeting (week 2) and the first project session (week 3) because these videos provided the most insight into how the robot ideas were generated.

Finally, over the course of the program, we documented student work through photographs and tracked the evolution of projects from initial ideas to final products. This process provided additional insight into the participation level and interests of the elementary students. It also served as evidence to support the claims made by students during their interviews.

Analysis

Our qualitative analysis of data proceeded in two phases. First, the interview and video data were transcribed for analysis, all names were replaced with pseudonyms, and the transcripts were rechecked against the original recordings for accuracy. The research team then met to identify and define both a priori codes drawn from the literature on identity (e.g., thinking of oneself as an engineer, being thought of by others as an engineer) and communities of practice (e.g., influence from peers, influence from role models, and working towards a shared goal), as well as emergent codes (e.g., attributes of the role models that made them influential, such as being knowledgeable, having admirable traits like kindness or patience, etc.) that became relevant during the process of data analysis (Strauss & Corbin, 1994). The a priori and emergent codes used for this analysis are presented in Table 4-2.

During the second phase, a subset of the research team, three of the six authors, conducted specific analyses relevant to each of our two research questions. We explored each question by examining the data as a collective and again by gender. To answer our first research question related to students' developing engineering identities, we compared responses in the pre- and post-program interviews. We investigated how the elementary students talked about themselves in relation to engineering. That is, we sought to determine the extent to which students viewed themselves, or thought others viewed them, as engineers. Their interview responses were further supported by documentation of their work throughout the entire program.

To answer our second research question exploring the role of community in the students' developing engineering identities, we analyzed students' interview responses related to the community established in the program via peer groups, role models, and shared goals (i.e., a collaborative robot group dance). While the post-interviews were the most informative for this analysis, there was some relevant information in the pre-program interviews, including students' motivations to join the program and definitions of role models. We also examined the intersection of communities of practice and engineering identity codes to determine whether the community aspect of the program impacted the students' engineering identities. Further, we looked for evidence to support or refute findings that emerged from the interviews with video data from the first design team meeting and project session between the elementary students and undergraduate engineers, using the same engineering identity and communities of practice codes.

Finally, we ensured the trustworthiness of our analysis in two ways. First, we triangulated the data using both interviews for each participant—before the start of the program and during the last week of the program—and additional sources of data—videos and student work. Second, we coded as a collective. After jointly defining all codes as a research team, three researchers coded the data in pieces individually, met together to discuss the assigned codes, and resolved all disagreements through discussion; the final coding reflected consensus.

Table 4-2

Codes Used for Qualitative Analyses of Interview Data

Topic	**Codes**	**Definition**
Engineering identity	Thinking of oneself as an engineer a. Describe self as an engineer b. Confidence in engineering ability c. Future goals in engineering d. Growth mindset e. Importance to self to be good at engineering	Students explain that they (a) consider themselves engineers in some respect, (b) have confidence in their engineering abilities, (c) are considering becoming engineers when they grow up, (d) think they will improve at engineering with more effort and time, or (e) think it is important to be good at engineering.
	Being thought of by others as an engineer	Students explain that someone else views them as engineers or believes they are capable in engineering.
Communities of practice	Influence from peers	Students describe a peer as one of the reasons they joined and/or engaged in the program.
	Influence from role models a. Admirable traits b. Knowledgeable c. Time together	Students describe the undergraduate engineers as role models because they are (a) kind, helpful, patient, dedicated, etc., or (b) knowledgeable and able to teach them about engineering. Or students express that they engaged in the program because of (c) their general experience collaborating with the undergraduate engineers.
	Working towards a shared goal	Students describe interest in working on a collaborative project with their peers and/or the undergraduate engineers.

Findings

Our findings related to changes in elementary students' interest in and understanding of engineering are organized into two sections. Each section addresses one of our research questions posed in the Introduction: elementary students' developing engineering identities and the role of community in the development of engineering identities.

Finding Set 1: Elementary Students' Developing Engineering Identities

To answer our first research question, we analyzed the manner in which elementary students discussed themselves in relation to engineering comparatively across their pre- and post- program interviews. In particular, we focused on the extent to which the students viewed themselves, and thought that others viewed them, as engineers. Overall, we found that all students identified more with engineering after their experience in the program and that this finding was consistent across gender.

Thinking of oneself as an engineer. At the start of the program, students had a good sense of what engineering entailed, describing engineers as creative designers and builders with strong technological skills. Some students were even able to talk about disciplines within engineering, for example, software, because their parents or other close family members were engineers. Furthermore, all students described having some experience with engineering prior to their involvement in this program. Yet, half of the students initially reported low levels of confidence in their engineering abilities and, except for one student who thought he was better than his peers at engineering, the remaining students thought that they were only mediocre. Similarly, 13 of the 14 students were hesitant to talk about themselves as engineers, stating that they either did not view themselves as engineers (half) or they were only "maybe", "kind of", or "sort of" engineers.

Sadie's experience in the Engineering Arts program was representative of half of the elementary student participants, those who exhibited low confidence in engineering prior to the program. Sadie did not initially identify as an engineer even though she had experience with robotics in another after-school program. In fact, her hesitations stemmed from her prior experiences with robotics. Sadie explained that she thought she was "a little worse" at engineering than her classmates and she only "sort of" thought she was an engineer. She elaborated, "I remember once I was trying to build something and it completely fell apart." However, by the end of the program, Sadie viewed her past experiences in a different light, explaining,

> I realized that once I looked back into my past, I was all like, wow, if I actually put my mind to it, I probably would have been able to finish [the robot] and not have it be all rickety and ugly.

She continued, "I learned that engineering is actually really easy when you put your mind to it." Sadie identified more as an engineer at the end of the Engineering Arts program because, alongside her peers, she experienced success in designing, 3D printing, and painting a unicorn head for her team's dancing unicorn robot (see Figure 4-3).

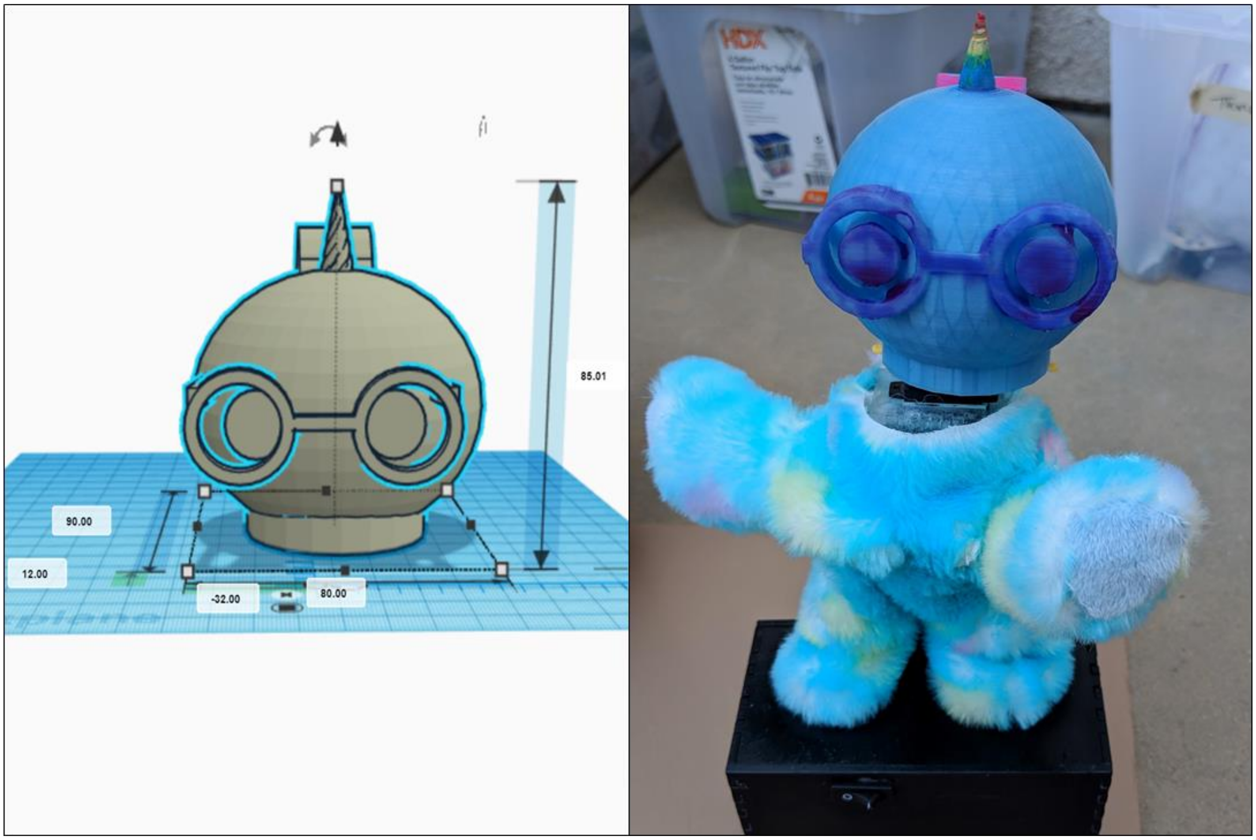

Figure 4-3. The 3D design for Sadie's robot head in TinkerCAD (left) and the completed robot (right).

Similarly, James began the program with low confidence and did not identify as an engineer, both because he did not have much engineering experience and because the experience he had had made him feel incompetent. James initially stated that he did not view himself as an engineer, "I don't do them [engineering projects] too often, and when I do do them, they don't turn out too good." James also expressed that he thought he was "a little bit worse" than his classmates at engineering. Like Sadie, James worked with his peers to create a robot head design in TinkerCAD that was 3D printed and painted for his team's dancing wolf robot (see Figure 4-4). And by the end of the program, James had started to identify more as an engineer. James explained that he felt more like an engineer after Engineering Arts, "I know how to do stuff on TinkerCad better since I explored it. … I really liked using

TinkerCad, and I learned that you shouldn't give up no matter how hard you have to work." He also gained confidence in his engineering skills, noting that the program was useful, "We can use it [engineering] later in life. Like say if something stops working, we could work to build a makeshift one in the meantime."

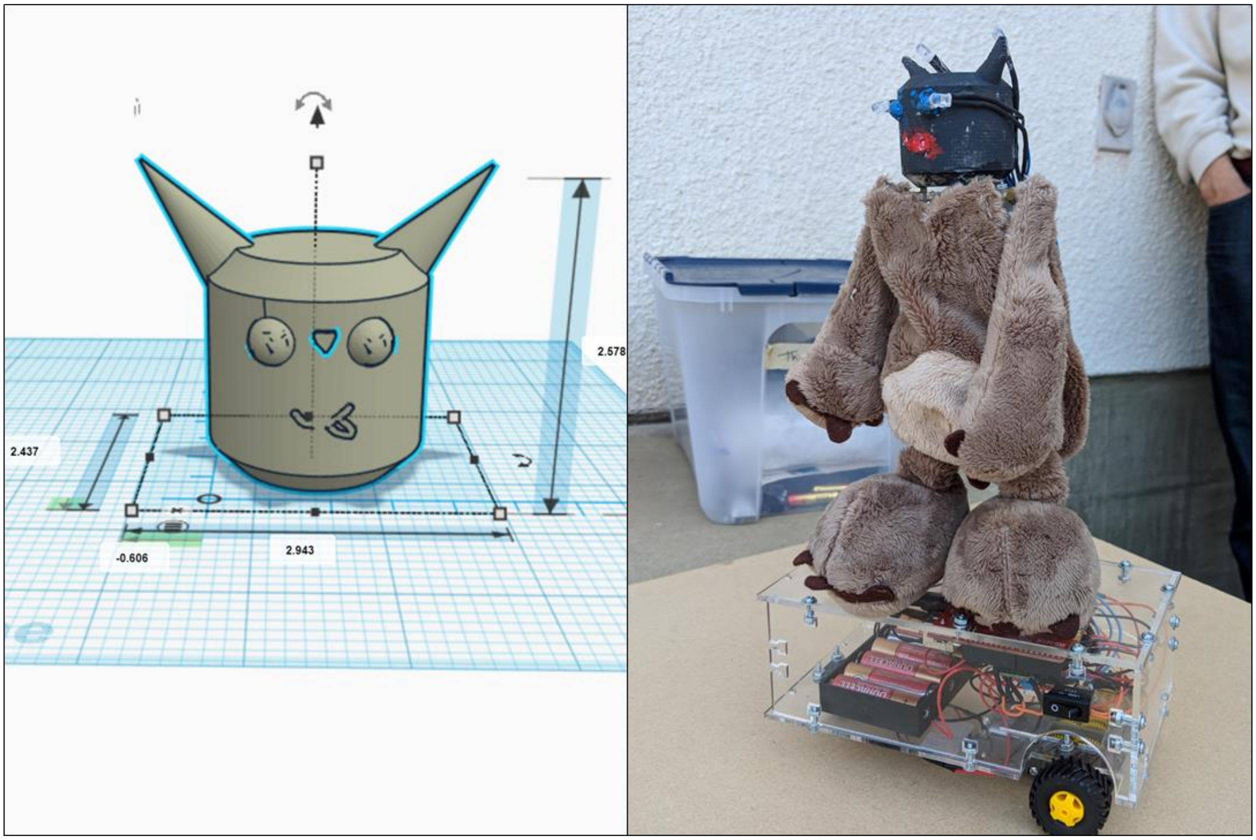

Figure 4-4. The 3D design for James' robot head in TinkerCAD (left) and the completed robot (right).

Both Sadie and James appeared to more closely identify with engineering at the end of the program because of the successes and support they experienced. Even those students who began the program feeling more confident in their engineering abilities grew as engineers over the 10 weeks. For example, Aman initially thought that he was "pretty good" at engineering because of his prior experience with robotics, saying, "I can do commands [to move robots]. I can move commands forward or backward. I can test for it." But Aman still thought that his experience doing engineering in this club "made me feel more like an engineer." In his post interview, he explained, "I learned more. Now if there's a wire that's broken in my circuit, I can fix it."

Being thought of by others as an engineer. While most of the students did not express concern over how others perceived them in relation to engineering, two students identified more as engineers *because* of how others viewed them. For example, Ernesto signed up for the program because he wanted to be able to help his father with his work, "I signed up for this program because my dad is a handyman and I want to help out his job. So I want to learn how to fix stuff and build stuff." By the end of the program, Ernesto identified more as an engineer because he was finally able to help his father:

> I used to not really know much about engineering, like with my dad, until this club. Now when I went to his work and he was doing LED lights on the pool and stuff, and he's like, "You want to help?" I'm like, "Yeah!"

Similarly, according to Deepti,

> I don't think I was an engineer before this club at all. I was just a normal, reading girl. But now I think after this club, it's so great to be in this club and be more of an engineer. … I'll be like, "Daddy, look at what I can do! I can do the same thing as you!"

Although neither Ernesto nor Deepti explicitly stated that their parents viewed them as engineers by the end of this program, it was evident that their identities as engineers were tied to their parents' perceptions of them on engineering-related tasks.

Finding Set 2: The Role of Community in the Development of Engineering Identities

To answer our second research question, we analyzed students' interview responses related to the engineering community of practice established in the program via peer groups, role models, and shared goals (i.e., collaborative robot group dance). This engineering community of practice was highly influential for engaging the students in engineering and contributed to the development of their engineering identities. While all students benefited from this community, we found that it was especially important for the girl participants.

Influence from peers. When asked about Engineering Arts program highlights, approximately two-thirds of the 14 student participants mentioned working with their peers in some capacity, including all six girls and three of the eight boys. Common responses included, "My friends were there and we got to build a lot of cool things together" (Brandisha) and "I liked planning out what our robot was going to be like with my friends" (Sean). Javier was especially influenced by his teammate: After explaining that this program "made me want to pursue my dream even more", Javier went on to say that he was inspired to become an engineer because of his partner, "It was my partner [that inspired me] because she helped me a lot and when she had an idea, I improved on it. And it just works on the fact that you work better with a team."

Although, aside from Javier, students did not mention their peers when discussing their engineering identities, their peers clearly helped them engage more in these engineering experiences, a prerequisite for identifying with engineering (Carlone, 2012). In particular, half of the girls cited their peers as motivating factors for joining the program, while only one of the eight boys mentioned peers. For example, Sadie explained that she was not initially interested in engineering and she only joined the program because of her friend, Jessica:

> I remember before I signed up to this class, I didn't really like engineering. But when I realized my friend, Jessica, was gonna do it, I'm all like, "Oh I'm gonna do it too because I could start to like engineering, too." And, so I signed up and it was really fun.

Interestingly, her friend, Jessica, was motivated to join the program because she was a relatively new student at the school and hoped to make new friends.

Influence from role models. Across the board, the elementary students described their undergraduate engineer partners, both the freshman and SWE engineers, as role models. In expressing their reasons, the majority of dialogue with the girls centered around the engineers' interpersonal qualities, such as kindness and dedication to helping. While several of the boys also mentioned similar positive qualities of their engineer partners, as a group, they more commonly described their partners as knowledgeable and helpful in teaching about engineering.

For example, in the post-program interview, Sahira described one of her freshman engineer partners, Janet, as "really funny" and went on to say that her favorite part of the program was "talking to Janet about what we were going to do cause that was really fun." This reason provided by Sahira for why she viewed Janet as a role model aligned well with her pre-program explanation of what she looked for in a role model: "Someone who cares about what you do. Someone who is nice to you."

Beyond laughing with Janet during the program, Sahira grew as an engineer because of their interactions and this was evident as early as the first design team meeting. After brainstorming ideas for their robots, Sahira, Deepti (Sahira's elementary teammate), and Janet settled on a unicorn that would dab (a dance move popular among elementary students) while spinning in circles. Janet gave each of the girls a piece of graph paper, a pencil, and a ruler to sketch a first draft of their robot (Figure 4-5) and written at the top of each paper was “Engineer’s name: ______”. As they began sketching, the following conversation ensued:

Sahira: Do I put your name?

Janet: No, your name.

Sahira: But it says, “Write engineer name.”

Janet: You’re an engineer!

Sahira: Oh! Oh, okay.

Deepti: (singing) We’re gonna be engineers. We already are engineers!

By the end of the program Sahira was more interested in and knowledgeable about engineering, “At first I had no idea like what engineering was or how it worked or like… I honestly didn’t like engineering. And now, after all of the fun things that happened, it was a lot of fun.” Furthermore, Sahira began to identify as an engineer for the first time after her experiences in this program and had plans to continue to participate in engineering activities, stating that she was “almost there [as an engineer]. Still many steps ahead of my future.”

Similarly, Jessica initially thought role models should be kind and good with kids. At the end of the program, she explained that she considered her SWE engineer partner a role model because she was nice and relatable, in that she had hobbies and interests outside of engineering. For example, according to Jessica, “They [the undergraduate engineers] kind of inspired me. Like Andrea, how she says she likes to rock climb, I like that she just experiences different things.” Like Sahira, Jessica began to identify with engineering for the first time by the end of the program. She explained, “My interest [in engineering] grew more [from this program], because at the beginning I remember talking to you and saying I liked it but I didn't really know much about it." After working on an engineering project alongside engineers, Jessica expressed that she was now considering a career in engineering and described engineering as a job that "just kind of helps change the world, in different ways."

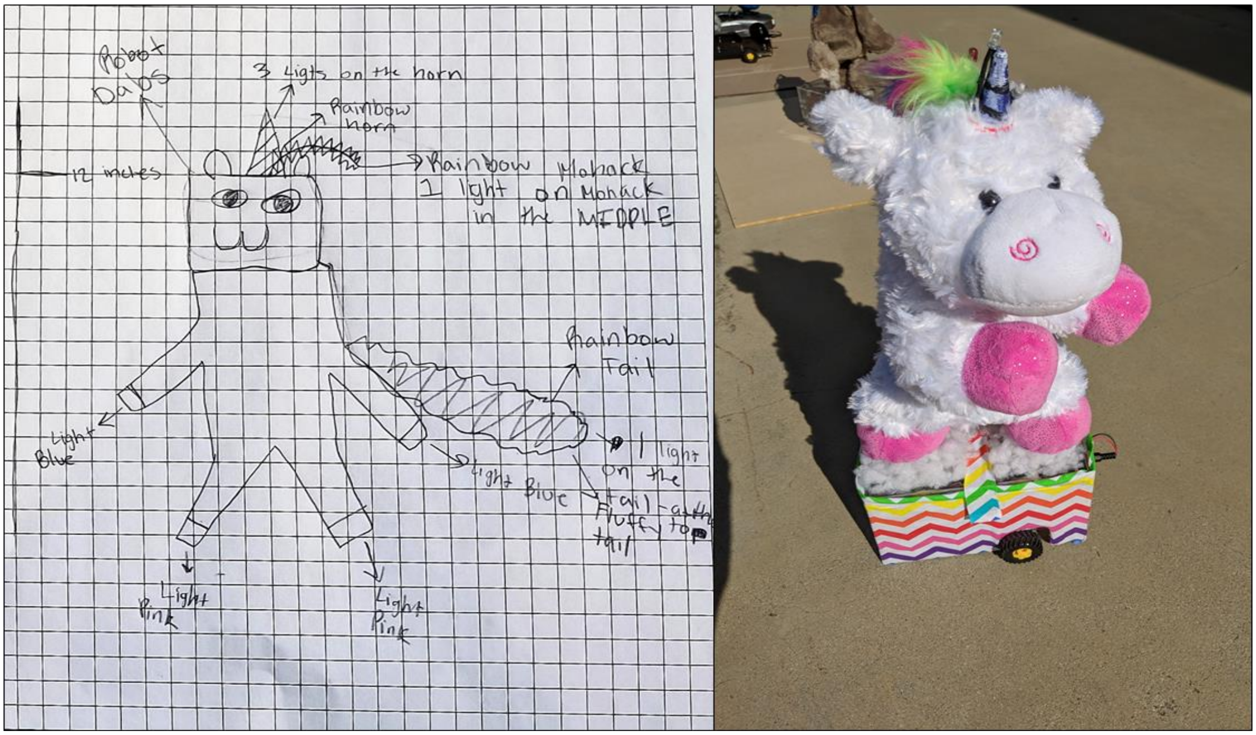

Figure 4-5. Sahira's unicorn robot engineering sketch from the first design team meeting (left) and the completed robot (right).

From the beginning of the program, Ethan described role models quite differently from Sahira and Jessica; Ethan was more concerned with technical knowledge than interpersonal skills. In his pre-program interview, he described the following as most important to him in a role model, "Working with the materials safely, showing us how to use them properly, and maybe knowing what to like experiment with, what's safe or not. So really safety pretty much, cause engineering can get dangerous." Similarly in the post-program interview, Ethan focused on technical knowledge. Ethan described one of his freshman engineer partners, Bernardo, as a role model to him because of how helpful he was in building the robot to his specifications and designs. In particular, according to Ethan, "He [Bernardo] could take all the like, um [feedback] well. He really did like exactly what we wanted with the robot."

One example of how Bernardo implemented feedback from Ethan on the robot design comes from the first design team meeting. There was sustained back-and-forth dialogue around the robot design between Ethan and Bernardo, along with Ethan's elementary partner, Aman, and Bernardo's undergraduate partner, Gabriela. The conversation was centered around the design of their DJ unicorn robot. Prior to the beginning of this excerpt, they discussed where the LED lights would be placed on the robot in reference to the DJ mixing table (see Figure 4-6).

Ethan: Right here [points at drawing]. So we have like a table and it goes down a tiny bit. And then I'm having it like on this side of that table.

Bernardo: Oh, okay, I get you.

Ethan: So there, so do like one light right there maybe.

Aman: And one like right there.

Ethan: Right there?

Aman: Yeah.

Gabriella: And one in the middle?

Ethan: And then, yeah, one in the middle.

Gabriella: I like that you're adding more lights over here (laughs).

Bernardo: Noooo (laughs).

Ethan: And then right there and right there, cause it'd be pointing up.

Gabriella: Well, this is like on the table.

Aman: We just have two more lights left.

Gabriella: So this is on the table and this is the turntable right here?

Ethan: Yeah.

Gabriella: Okay.

Bernardo: So these are the lights, kind of like a car, right?

Aman: Yeah.

Ethan: Yes, exactly.

Bernardo: Okay, I get you. Yeah, just do a circle, yeah. Cause this is the, what we're seeing, cause it's the front.

Ethan: Alright.

Gabriella: Oh I see, okay.

Ethan: And then, so then, and then we're going to do legs [of the unicorn], so…

Gabriella: Draw like a pole real quick.

Ethan: This leg's going to be moving. This one's just like a normal leg.

The discussion then shifted towards how the unicorn's leg would move. By the end of the meeting, the team had created a comprehensive shared vision of what the robot would look like and how it would move. This experience working with engineers who valued his input *as an engineer* helped Ethan continue to grow and identify as an engineer. He explained that his experience in this program made him feel more like an engineer because of everything he learned with the undergraduate engineers: "I learned how to connect a circuit and how… many things. A lot of new electric [things]. I learned how to use LEDs. … I learned a lot about how motors work."

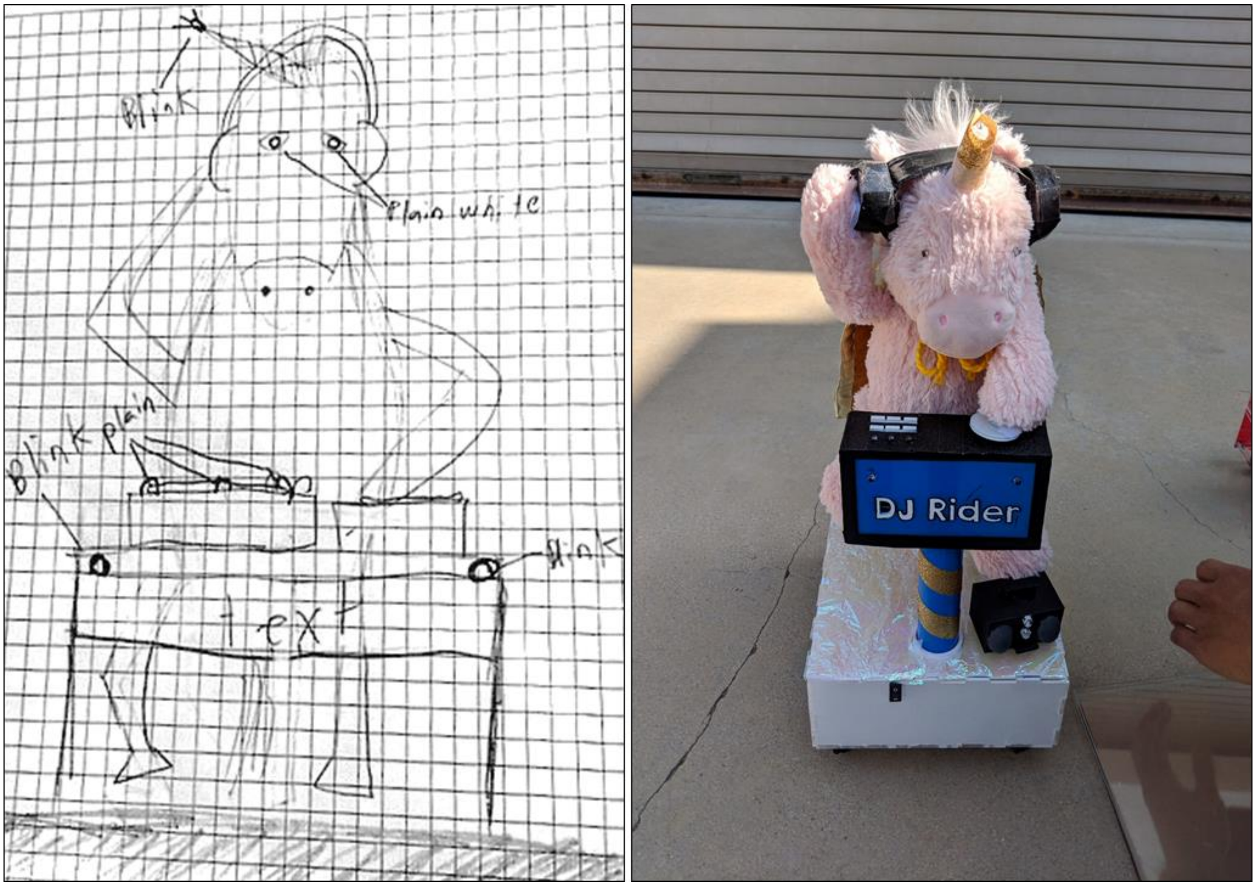

Figure 4-6. Ethan’s DJ unicorn robot engineering sketch from the first design team meeting (left) and the completed robot (right).

Working towards a shared goal. As we have described throughout the paper, the ultimate goal of this project-based engineering program was to design and help build a robot that would dance as part of a larger robot dance show. A collaborative group dance runs counter to most engineering projects, which more commonly center around competitions. We found that the students preferred the dance to a competition: All of the girls and five of the eight boys had strong preferences for a collaborative, versus competitive, final project; two of the boys did not care either way; and one boy would have preferred a competition. As one example, Sadie thought having students build robots that danced together was better than having students compete over building the best robot:

> I feel like the dance is a better idea [than a competition], because a competition, they're really competitive. I mean, you could actually lose a friend because of that. You'd be like, "Oh, our robot's better! Your robot's the worst!" And you could easily lose a friend.

As a second example, Jessica explained, "I like that [dancing together] more, because competing can put you down to, 'Oh, our robot wasn't good enough. It lost.'" And as a third example, Javier noted, "Well, it's just like us. We still need each other. Plus if there's more robots, there's more to focus on. It makes the performance shine more."

Discussion

Although the benefits of teamwork for engaging girls in engineering have been well documented (Busch-Vishniac & Jarosz, 2004; Cunningham & Lachapelle, 2014; Goodman et al., 2002; Menekse et al., 2017), research related to the impact of engineer role models and collaborative project goals on elementary students' engineering identities is more scarce. The present study builds on the existing literature by providing a detailed analysis of the experiences of 14 fifth-grade students, 6 girls and 8 boys, as they moved through a 10-week, community-based engineering program run in partnership with engineering students from a nearby university. Below, we discuss the implications of each of our three tiers of community in detail.

We found that students' peers were integral to the success of this program for two reasons. First, several students, mostly girls, who were not initially interested in engineering only joined the program to spend time with their friends. However, all of these students engaged in every aspect of the program and, by the end, began to identify as engineers. Second, many of the students, again the majority of whom were girls, reported time with their peers as a program highlight. Engaging with engineering is a necessary step in identifying with engineering and, thus, creating collaborative spaces where students can interact is essential for helping students develop identities as engineers.

The elementary students in our study were also heavily influenced by working with undergraduate engineers. All students viewed their undergraduate partners as engineer role models and engaged more in engineering because of the relationships they developed. In line with Buck et al.'s (2008) research, we found that the engineers' interpersonal skills were most essential to their positive influence on the girls. All six girls were more impacted by the engineers' kindness and dedication to helping than they were by their knowledge of engineering. Our findings extend the existing research (e.g., Buck et al., 2008) by comparing the cognitive processes used by girls and boys to identify engineer role models. We discovered that while several of the boys were also impacted by the role models' interpersonal traits, as a group, they were more influenced by the technical skills they learned from the engineers. As such, to benefit the most students, it is important to seek out engineer role models who are capable of both relating to students on a personal level and demonstrating their knowledge of the field.

Finally, designing the program around a shared, collaborative final project helped to engage more students, especially girls, in engineering. All of the girls and over half of the boys in our program preferred working towards the shared goal of a robot flash mob to the idea of a robotics competition. Students passionately advocated for collaborative engineering projects, citing that competitions make people feel bad about themselves and hurt friendships. These findings extend the literature on collaboration beyond teamwork (e.g., Menekse et al., 2017) by highlighting the value of increasing inter-team collaboration in elementary engineering programs.

The results from our study suggest that engineering communities of practice can help more students engage in and identify with engineering. When these communities, consisting of peers and role models, are designed around shared goals, girls are especially likely to construct identities as engineers. Consistent with feminist theories of scientific knowledge, our findings suggest that highlighting the social aspects of engineering, alongside the technical, may contribute to the narrowing of the gender gap.

Conclusions

In this study, we examined how an engineering community of practice, developed through a partnership program with undergraduate engineering students, influenced the degree to which elementary students identified with engineering. In particular, we explored the impacts of three tiers of the community on students' identities as engineers: peer groups, role models, and inter-group collaboration. Through an analysis of pre-post interviews, select weekly video recordings, and documentation of student work, we found that our 10-week partnership program was successful in helping elementary students construct identities as engineers. The students' identities as engineers were positively impacted by engaging in engineering with their peers, bonding with and learning from their engineer role models, and working as a cohort towards the shared goal of a robot flash mob. While all students benefited from the engineering partnership, the girls were notably more influenced by community aspects of the program. First, the girls more commonly reported joining the program to spend time with their peers than the boys, who mostly joined to gain engineering experience. Second, the girls were more influenced by the personal bonds they developed with the role models than the boys, who cared most about the undergraduates' knowledge of engineering. Finally, the girls unanimously and passionately advocated for inter-group collaboration on engineering projects, while two of the boys were indifferent to the issue and one preferred competition.

Although previous studies have pointed to benefits of teamwork and role models on engaging diverse groups of students in STEM, few have researched elementary engineering programs, and fewer still have compared across gender or extended the element of collaboration beyond individual teams to an entire cohort. Our findings build on the existing research and suggest that engineering communities of practice, which promote intra- and inter-group collaboration among peers and role models, can help encourage more students and especially more girls to identify as engineers. However, the conclusions that can be drawn from this study are limited by our sample size and data. While the experiences of 6 girls and 8 boys serves as an important starting point for understanding the role of community on students' developing identities as engineers, more work needs to be done. Additionally, there is a need for longitudinal studies following the experiences of the students as they enter high school and move on to college and the workforce to fully understand the impact of the program on the engineering gender gap. This study captured the second year of a partnership program that is set to run indefinitely and thus will provide ample opportunity for continued data collection. Further, we urge other researchers to consider investigating the longitudinal impacts of community on elementary students' developing engineering identities.

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Chapter 5: *Conclusions*

The goal of this research was to understand both the barriers to participation and success in engineering, as well as effective curricular approaches to reduce these barriers, thereby helping to increase diversity and reduce attrition in engineering programs. To identify the most common barriers, this study began by analyzing the experiences of 176 engineering undergraduates (all new students, mostly freshmen). These students described, through surveys, the experiences in their lives that led them to major in engineering and went on to explain their current values for and competence beliefs in engineering. This analysis, which helped identify common barriers faced by women in engineering, was followed by research around inclusive engineering course design. The context for this work was a partnership program between a freshman mechanical engineering course and an afterschool program at a nearby elementary school. We explored the impact of this novel partnership on both the engineering undergraduates and the elementary students though pre- and post- interviews with 10 undergraduates and 14 elementary students, video recorded sessions with 4 undergraduates and 4 elementary students, as well as documentation of the students' work over the course of the program. Three major themes were identified through the analysis of this data.

First, barriers to entry and success in engineering for women began early and were unrelenting. Male engineering students were significantly more likely to cite engineering play as a motivator for majoring in engineering, whereas female engineering students were less commonly exposed to engineering in their early childhood. These women who chose to pursue engineering, on the other hand, were more likely to have been influenced by experiences with mentors later in their adolescence. Once enrolled in engineering undergraduate programs, gender was the most significant predictor of engineering competence beliefs. Equally capable and experienced women had significantly lower beliefs in their engineering abilities and lower expectancies for future success, suggesting that these competent women are less likely to persist in engineering than their male peers.

Second, well designed undergraduate engineering curricula can substantially help boost engineering students' self-efficacy beliefs. The analysis of the focal mechanical engineering course revealed that several components of this course, in particular, contributed to students' increased levels of confidence in their abilities and expectations for success: scaffolded and project-based learning, grounded in work with clear connections to engineering as a career. The course was designed to support student learning by scaffolding hands-on projects through weekly lab sessions. These weekly projects helped the freshman engineering students, who were novices in the field, gain necessary mastery experiences to feel competent and capable of completing their final course project on their own. The final project entailed the construction of a dancing robot, designed to the specifications set forth by clients. Fifth- and sixth-grade students served as the clients for this course and proved to be highly effective in this role. The undergraduate engineering students explained that working with the clients made them feel like professional engineers. As an added bonus, the elementary students looked up to the undergraduates and viewed them as real engineers, further increasing their confidence in their abilities and their perceptions of themselves as professionals.

Third, highly collaborative engineering programs which leverage peer groups, role models, and inter-group collaboration can help elementary students develop identities as engineers; and this was especially impactful for girls. At the end of the 10-week engineering program, all of the students were more engaged in engineering because of the peer work. And notably, many of the girls described joining the program solely to spend time with their peers. Yet these girls, once enrolled, all reported positive experiences and future interest in engineering. Further, the students were all positively influenced by the relationships they developed with the engineering undergraduates who served as role models for this program. The girls were most impacted by the personal bonds they developed with the engineering students, while the boys were more interested in their knowledge of engineering. And finally, all of the girls and most of the boys described relief and excitement over the collaborative (as opposed to competitive) final project, whereby the robots came together for a flash mob dance.

As is the case with any study, there are several limitations that must be considered when interpreting the findings from this work. With regards to the quantitative survey study, the conclusions were limited by the sample size, especially the low ratio of women to men. While future work should test the findings with a larger population of engineering undergraduates, the disproportionate number of men will remain a problem, which circles back to the very issue this dissertation set forth to address: Too few women are choosing to major in engineering. Similarly, with regards to the qualitative work, the findings were limited by the sample size. While the experiences of 10 undergraduates and 14 elementary students serves to provide an important starting point for understanding the impact of redesigned engineering curricula on students' beliefs in their abilities and identities as engineers, more work needs to be done. Not only is it important to replicate this work with additional students, but the impact of the course should also be explored over time through longitudinal studies.

Nonetheless, the findings from this dissertation have clear implications for the field of engineering education to help overcome existing barriers to reduce the gender gap in engineering. First, it is important that women are exposed to engineering as young girls at rates comparable to young boys. This work suggests that highly collaborative engineering programs which leverage peer groups, role models, and inter-group collaboration are especially effective at engaging girls. Second, to reduce attrition of women from engineering programs it is necessary to address their growth as engineers as part of the curriculum through inclusive instructional design. Scaffolded and project-based learning, especially when designed with clear connections to engineering as a career, can be highly effective at increasing students' beliefs in themselves. Finally, creating university-elementary school partnerships serves as a great pathway to overcoming the barriers faced by girls and women, and likely other underrepresented groups, in engineering. These partnerships are mutually beneficial for both groups involved. Elementary students who otherwise have no (or limited) exposure to engineer role models are given the opportunity to learn from engineering students, who they view and real engineers. And freshman engineering students who would otherwise have no (or limited) exposure to industry clients, are given the real-world experience of client-led design. In sum, when freshman engineering courses partner with elementary schools to serve the needs of both groups, everyone wins.

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Appendix A: Engineering Student Surveys

Both surveys were conducted online using Qualtrics[1].

Pre-program survey questions:

1. Full (first and last) name:
2. Please be advised that you may be photographed and/or videotaped as part of this course. If you give permission, your photograph or clips from the video may be used publicly to promote this course and/or research associated with the educational goals of this course. This means that the images and/or video clips may be used in research publications, on research/university websites, and/or at research conferences.
    a. I give permission for photos and/or video clips with me in them to be used
    b. I only give permission for photos (NOT video clips) with me in them to be used
    c. I only give permission for video clips (NOT photos) with me in them to be used
    d. I do NOT give permission for photos or video clips with me in them to be used
3. Thank you for your willingness to take my questionnaire! I realize that your time is extremely valuable, and I sincerely appreciate your input. The primary purpose of this research is to understand the values and experiences of engineering students at UCSB to ensure that courses are designed to help all students succeed in their degrees and subsequent careers. Your feedback on this study will help to inform recommendations to the university, and the engineering education community in general, pertaining to how to better educate and prepare future engineers. Once the questionnaire responses are collected, your name will be replaced with a pseudonym, so your responses will be confidential. Only approved researchers will have access to this list and the data collected. Your responses will not be released to any of your professors with any identifying information, so please answer honestly. There are no foreseeable risks to your participation in this questionnaire. The potential benefits include contributions towards recommended changes for the future of engineering education. I anticipate this questionnaire to take you approximately 5-10 minutes. Your participation is voluntary, and your responses are confidential; they will not be reported in any manner that will identify you. If you have any questions regarding your participation in this research, please contact Mandy McLean at amclean@ucsb.edu. Additionally, if you complete this questionnaire but you do

[1] Link to pre- and post-program Qualtrics surveys are available: https://goo.gl/dxsoqJ and https://goo.gl/WjMHiA.

NOT want your confidential responses used for research purposes, please email Mandy and your responses will not be used. If you have questions regarding your rights as a participant, any concerns regarding this project or any dissatisfaction with any aspect of this study, you may report them to the human Subjects Coordinator Office of Research, 3227 Cheadle Hall UCSB Santa Barbara, CA 93106-2050, (805) 893-3807.

   a. Click here to indicate you have read the statement above and agree to participate in the questionnaire.

4. The following statements relate to your experiences with building and/or creating things (scale: disagree, somewhat disagree, somewhat agree, agree):
   a. Building/creating is interesting/fun
   b. Building/creating is useful for my life outside of school
   c. Building/creating is useful for what I plan to do after I graduate
   d. It's important to me that I am good at building/creating
   e. It's important to me that others see me as good at building/creating
   f. I feel that I am already good at building/creating
   g. Compared to other students in my undergraduate program, I feel that I am one of the best at building/creating
   h. With effort, I think I could get even better at building/creating things
5. The following statements relate to your experiences using creativity to solve problems (scale: disagree, somewhat disagree, somewhat agree, agree):
   a. Creatively solving problems is interesting/fun
   b. Creatively solving problems is useful for my life outside of school
   c. Creatively solving problems is useful for what I plan to do after I graduate
   d. It's important to me that I am good at creatively solving problems
   e. It's important to me that others see me as good at creatively solving problems
   f. I feel that I am already good at creatively solving problems
   g. Compared to other students in my undergraduate program, I feel that I am one of the best at creatively solving problems
   h. With effort, I think I could get even better at creatively solving problems
6. The following statements relate to your experiences working as part of a team (scale: disagree, somewhat disagree, somewhat agree, agree):
   a. Working as part of a team is interesting/fun
   b. Working as part of a team is useful for my life outside of school
   c. Working as part of a team is useful for what I plan to do after I graduate
   d. It's important to me that I am good at working as part of a team
   e. It's important to me that others see me as good at working as part of a team
   f. I feel that I am already good at working as part of a team

g. Compared to other students in my undergraduate program, I feel that I am one of the best at working as part of a team
h. With effort, I think I could get even better at working as part of a team

7. The following statements relate to your experiences doing work that improves your community (or society in general) (scale: disagree, somewhat disagree, somewhat agree, agree):

    a. Helping society with my work is interesting/fun
    b. Helping society with my work is useful for my life outside of school
    c. Helping society with my work is useful for what I plan to do after I graduate
    d. It's important to me that I am good at helping society with my work
    e. It's important to me that others see me as good at helping society with my work
    f. I feel that I am already good at helping society with my work
    g. Compared to other students in my undergraduate program, I feel that I am one of the best at helping society with my work
    h. With effort, I think I could get even better at helping society with my work

8. The following statements relate to your experiences with engineering (in general) (scale: disagree, somewhat disagree, somewhat agree, agree):

    a. Engineering is interesting/fun
    b. Engineering is useful for my life outside of school
    c. Engineering is useful for what I plan to do after I graduate
    d. It's important to me that I am good at engineering
    e. It's important to me that others see me as good at engineering
    f. I feel that I am already good at engineering
    g. Compared to other students in my undergraduate program, I feel that I am one of the best at engineering
    h. With effort, I think I could get even better at engineering
    i. Compared to most other school subjects, I am better at engineering
    j. I consider myself to be an engineer

9. How likely is it that you will be doing each of the following upon graduation? (scale: most likely not, probably not, possibly, most likely yes):

    a. Attending graduate school within engineering
    b. Working in industry as an engineer
    c. Working at a not-for-profit engineering organization doing community development work
    d. Working as a teacher in an engineering-related subject (e.g., math, science)
    e. Working in an engineering-related role concerning public policy, government, or law

    f. Using engineering as a stepping stone to a different degree (e.g., medicine, business, law)
    g. Working at something outside of the field of engineering

10. Are you involved in any Engineering Student Organizations? If so, please list them below.
11. Are you a part of any mentoring programs, as either a mentor or a mentee?
    a. Yes, as a mentor in:
    b. Yes, as a mentee in:
    c. No
12. Do you regularly volunteer with any programs? If so, please list them below.
13. Please select all course below that you have already completed or are currently enrolled in at UCSB.
    a. CHEM 1A or 2A
    b. CHEM 1AL or 2AC
    c. CHEM 1B or 2B
    d. CHEM 1BL or 2BC
    e. CHEM 1C or 2C
    f. CHEM 1CL or 2CC
    g. CHEM ENGR 5
    h. CMPSC 8
    i. CMPSC 16
    j. CMPSC 24
    k. ECE 1A
    l. ECE 1B
    m. ECE 5
    n. ENGR 3
    o. MATH 3A
    p. MATH 3B
    q. MATH 4A
    r. MATH 4AI
    s. ME 10
    t. ME 12S
    u. PHYS 1
    v. PHYS 2
14. Do any of your close family members hold an engineering degree?
    a. Yes
    b. No

c. Unsure

15. Which of the following would you consider influential in your decision to enroll in an engineering program? (please select all that apply)
    a. Role model or mentor encouraged me/inspired me
    b. Previous experience building/creating things
    c. Childhood engineering-type toys (e.g., LEGOs)
    d. Prior classes (high school or even earlier)
    e. Informal experiences with engineering-type activities (e.g., summer programs or museums)
    f. A desire to help society through engineering work
16. Which engineering discipline do you most closely align yourself with?
    a. Chemical engineering
    b. Computer engineering
    c. Computer science
    d. Electrical engineering
    e. Mechanical engineering
    f. NA: I am not an engineering student
17. What year are you in your degree? (freshman, sophomore, junior, senior, fifth-year senior or more, graduate student)
    a. Freshman
    b. Sophomore
    c. Junior
    d. Senior
    e. Fifth-year senior or more
18. What gender do you most closely align with?
    a. Male
    b. Female
    c. Other: ______
19. What race/ethnicity do you most closely identify with? You can select more than one.
    a. American Indian or Alaskan Native
    b. Asian or Asian American
    c. Black or African American
    d. Hispanic or Latino/a
    e. Native Hawaiian or Pacific Islander
    f. White
    g. Other: ______

20. What is your approximate college GPA currently? Please estimate on a 4.0 scale. Note: A or A+ =4.0; A- =3.7; B+ =3.3; B =3.0; B- =2.7; C+ =2.3; C =2.0; C- =1.8; D+ = 1.3; D = 1.0; D- =0.7; F=0.0.

Post-program survey questions:

1. Full (first and last) name:
2. Did you interact directly with your customers (elementary students at IV) at either of the three design team meetings throughout the quarter?
    a. Yes, at all three meetings
    b. Yes, at 2 of the 3 meetings
    c. Yes, at 1 of the 3 meetings
    d. No
3. Thank you for your willingness to take my questionnaire! I realize that your time is extremely valuable, and I sincerely appreciate your input. The primary purpose of this research is to understand the values and experiences of engineering students at UCSB to ensure that courses are designed to help all students succeed in their degrees and subsequent careers. Your feedback on this study will help to inform recommendations to the university, and the engineering education community in general, pertaining to how to better educate and prepare future engineers. Once the questionnaire responses are collected, your name will be replaced with a pseudonym, so your responses will be confidential. Only approved researchers will have access to this list and the data collected. Your responses will not be released to any of your professors with any identifying information, so please answer honestly. There are no foreseeable risks to your participation in this questionnaire. The potential benefits include contributions towards recommended changes for the future of engineering education. I anticipate this questionnaire to take you approximately 5-10 minutes. Your participation is voluntary, and your responses are confidential; they will not be reported in any manner that will identify you. If you have any questions regarding your participation in this research, please contact Mandy McLean at amclean@ucsb.edu. Additionally, if you complete this questionnaire but you do NOT want your confidential responses used for research purposes, please email Mandy and your responses will not be used. If you have questions regarding your rights as a participant, any concerns regarding this project or any dissatisfaction with any aspect of this study, you may report them to the Human Subjects Coordinator Office of Research, 3227 Cheadle Hall UCSB Santa Barbara, CA 93106-2050, (805) 893-3807.

    a. Click here to indicate you have read the statement above and agree to participate in the questionnaire.

4. The following statements relate to your experiences with building and/or creating things (scale: disagree, somewhat disagree, somewhat agree, agree):
    a. Building/creating is interesting/fun
    b. Building/creating is useful for my life outside of school
    c. Building/creating is useful for what I plan to do after I graduate
    d. It's important to me that I am good at building/creating
    e. It's important to me that others see me as good at building/creating
    f. I feel that I am good at building/creating
    g. Compared to other students in my undergraduate program, I feel that I am one of the best at building/creating
    h. With effort, I think I could get even better at building/creating things
5. The following statements relate to your experiences using creativity to solve problems (scale: disagree, somewhat disagree, somewhat agree, agree):
    a. Creatively solving problems is interesting/fun
    b. Creatively solving problems is useful for my life outside of school
    c. Creatively solving problems is useful for what I plan to do after I graduate
    d. It's important to me that I am good at creatively solving problems
    e. It's important to me that others see me as good at creatively solving problems
    f. I feel that I am good at creatively solving problems
    g. Compared to other students in my undergraduate program, I feel that I am one of the best at creatively solving problems
    h. With effort, I think I could get even better at creatively solving problems
6. The following statements relate to your experiences working as part of a team (scale: disagree, somewhat disagree, somewhat agree, agree):
    a. Working as part of a team is interesting/fun
    b. Working as part of a team is useful for my life outside of school
    c. Working as part of a team is useful for what I plan to do after I graduate
    d. It's important to me that I am good at working as part of a team
    e. It's important to me that others see me as good at working as part of a team
    f. I feel that I am good at working as part of a team
    g. Compared to other students in my undergraduate program, I feel that I am one of the best at working as part of a team
    h. With effort, I think I could get even better at working as part of a team
7. The following statements relate to your experiences doing work that improves your community (or society in general) (scale: disagree, somewhat disagree, somewhat agree, agree):

a. Helping society with my work is interesting/fun
b. Helping society with my work is useful for my life outside of school
c. Helping society with my work is useful for what I plan to do after I graduate
d. It's important to me that I am good at helping society with my work
e. It's important to me that others see me as good at helping society with my work
f. I feel that I am good at helping society with my work
g. Compared to other students in my undergraduate program, I feel that I am one of the best at helping society with my work
h. With effort, I think I could get even better at helping society with my work

8. The following statements relate to your experiences with engineering (in general) (scale: disagree, somewhat disagree, somewhat agree, agree):

    a. Engineering is interesting/fun
    b. Engineering is useful for my life outside of school
    c. Engineering is useful for what I plan to do after I graduate
    d. It's important to me that I am good at engineering
    e. It's important to me that others see me as good at engineering
    f. I feel that I am good at engineering
    g. Compared to other students in my undergraduate program, I feel that I am one of the best at engineering
    h. With effort, I think I could get even better at engineering
    i. Compared to most other school subjects, I am better at engineering
    j. I consider myself to be an engineer
    k. We use this statement to discard the survey of people who are not reading the questions. Please select 'somewhat agree' for this question to preserve your answers.

9. How likely is it that you will be doing each of the following upon graduation? (scale: most likely not, probably not, possibly, most likely yes):

    a. Attending graduate school within engineering
    b. Working in industry as an engineer
    c. Working at a not-for-profit engineering organization doing community development work
    d. Working as a teacher in an engineering-related subject (e.g., math, science)
    e. Working in an engineering-related role concerning public policy, government, or law
    f. Using engineering as a stepping stone to a different degree (e.g., medicine, business, law)
    g. Working at something outside of the field of engineering

10. How much do you attribute your experience in ME10 with Dr. Susko to your feelings about the following? (scale: less impactful than other courses, equally impactful to other courses, more impactful than other courses):

    a. How much you enjoy doing engineering (in general)
    b. How useful you consider engineering skills (in general) to be for your life outside of school
    c. How useful you consider engineering skills (in general) to be for your future career
    d. How important it is to you to be good at engineering
    e. How important it is to you that others view you as good at engineering
    f. How good you think you are at engineering (in general)
    g. How good you think you are compared to your peers in your engineering program
    h. How capable you think you are of learning new things in engineering
    i. The degree to which you consider yourself to be an engineer
    j. How successful you think you will be in your future career

11. Did you complete the pre-quarter survey for this class?

    a. Yes
    b. No

    Skip To: Q18 If Did you complete the pre-quarter survey for this class? = Yes

12. Please select all course below that you have already completed or are currently enrolled in at UCSB.

    a. CHEM 1A or 2A
    b. CHEM 1AL or 2AC
    c. CHEM 1B or 2B
    d. CHEM 1BL or 2BC
    e. CHEM 1C or 2C
    f. CHEM 1CL or 2CC
    g. CHEM ENGR 5
    h. CMPSC 8
    i. CMPSC 16
    j. CMPSC 24
    k. ECE 1A
    l. ECE 1B
    m. ECE 5
    n. ENGR 3
    o. MATH 3A
    p. MATH 3B

q. MATH 4A
r. MATH 4AI
s. ME 10
t. ME 12S
u. PHYS 1
v. PHYS 2

13. What year are you in your degree? (freshman, sophomore, junior, senior, fifth-year senior or more, graduate student)

    a. Freshman
    b. Sophomore
    c. Junior
    d. Senior
    e. Fifth-year senior or more

14. Do any of your close family members hold an engineering degree?

    a. Yes
    b. No
    c. Unsure

15. Which of the following would you consider influential in your decision to enroll in an engineering program? (please select all that apply)

    a. Role model or mentor encouraged me/inspired me
    b. Previous experience building/creating things
    c. Childhood engineering-type toys (e.g., LEGOs)
    d. Prior classes (high school or even earlier)
    e. Informal experiences with engineering-type activities (e.g., summer programs or museums)
    f. A desire to help society through engineering work

16. What gender do you most closely align with?

    a. Male
    b. Female
    c. Other: _____

17. What race/ethnicity do you most closely identify with? You can select more than one.

    a. American Indian or Alaskan Native
    b. Asian or Asian American
    c. Black or African American
    d. Hispanic or Latino/a
    e. Native Hawaiian or Pacific Islander

f. White
g. Other: _____

18. Are you involved in any Engineering Student Organizations? If so, please list them below.

19. Are you a part of any mentoring programs, as either a mentor or a mentee?

    a. Yes, as a mentor in:
    b. Yes, as a mentee in:
    c. No

20. Do you regularly volunteer with any programs? If so, please list them below.

21. What is you major (and minor, if applicable)?

22. Please explain why you chose your current major and be as detailed as possible.

23. Are you a transfer student?

    a. Yes
    b. No
    c. Decline to answer

24. Are you a first-generation college student? i.e., Are you the first person to go to a 4-year college in your immediate family?

    a. Yes
    b. No
    c. Decline to answer

25. What is your approximate college GPA currently? Please estimate on a 4.0 scale. Note: A or A+ =4.0; A- =3.7; B+ =3.3; B =3.0; B- =2.7; C+ =2.3; C =2.0; C- =1.8; D+ = 1.3; D = 1.0; D- =0.7; F=0.0.

Appendix B: R Code for Chapter 2 Analyses

```
#Upload data
	dat<-read.csv(file="C:/Users/Mandy McLean/Data/AnalyzingR/Paper2Data-R -
	Paper2Data-R.csv", header=TRUE, sep=",")
	colnames(dat)[1]<-"Duration"
#Clean data
#Keep only pre-responses
	dat <- dat[dat$Pre==1,]
#Keep only responses with GPA
	dat <- dat %>% drop_na(GPA)
#Dedupe
	library(dplyr)
	dat <- distinct(dat,Perm, .keep_all= TRUE)
#Add competence beliefs and values constructs to dataset
	dat <- dat %>%
	mutate(Comp=(EngGood+EngComp+EngGrow+EngCompSub+EngIAm)/5)
	dat <- dat %>%
	mutate(Value=(EngFun+EngUSeLife+EngUseFut+EngImpMe+EngImpOth)/5)
#Check Cronbach Alphas
	library(psy)
	Comp=data.frame(dat$EngGood,dat$EngComp,dat$EngGrow,dat$EngCompSub,dat
	$EngIAm)
	cronbach(Comp)
	Value=data.frame(dat$EngFun,dat$EngUSeLife,dat$EngUseFut,dat$EngImpMe)
	cronbach(Value)
#Convert to binary outcome (Comp>2 or not)
	dat <- dat %>% mutate(Comp.bi = ifelse(Comp>=3, 1, 0))
	dat <- dat %>% mutate(Value.bi = ifelse(Value>=3, 1, 0))
#Logistic regression
#Check for multivollinearity in independent variable
	library(usdm)
	dat.log=data.frame(dat$Female,dat$URM,dat$GPA,dat$Fresh,dat$ME,dat$CE,dat$
	CS,dat$EE,dat$Chem,dat$First,dat$Org,dat$Fam)
	cor.dat.log <- round(cor(dat.log, use = "pair"), 2)
	vif(dat.log)
	glm.comp =
	glm(Comp.bi~Female+URM+GPA+Fresh+ME+CE+CS+EE+Chem+First+Org+Fa
	m, data=dat, family=binomial(link="logit"))
	summary(glm.comp)
```

```
glm.value =
glm(Value.bi~Female+URM+GPA+Fresh+ME+CE+CS+EE+Chem+First+Org+Fa
m, data=dat, family=binomial(link="logit"))
summary(glm.value)
#Get the odds ratio
require(MASS)
cbind(coef(glm.comp), exp(coef(glm.comp)), exp(confint(glm.comp)))
cbind(coef(glm.value), exp(coef(glm.value)), exp(confint(glm.value)))
#Create histograms for Values contruct
hist(dat$Value, xlab="Values construct (N=139)", ylab="Count", col="lightgrey")
hist(dat$Value[dat$Female==1], xlab="Values construct: Women (N=31)",
ylab="Count", col="lightgrey", xlim=range(2.8,4.0))
hist(dat$Value[dat$Female==0], xlab="Values construct: Men (N=107)",
ylab="Count", col="lightgrey",xlim=range(2.8,4.0))
#Influence
#Compare by gender
dat %>%
  group_by(Female) %>%
  summarise(
    mot.classes = mean(na.omit(Classes)),
    mot.help = mean(na.omit(Help)),
    mot.rolem = mean(na.omit(RoleM)),
    mot.prior = mean(na.omit(PriorExp)),
    mot.childhood = mean(na.omit(Childhood)),
    mot.informal = mean(na.omit(InformalExp)))
wilcox.test(dat$Classes[dat$Female==1], dat$Classes[dat$Female==0])
wilcox.test(dat$Help[dat$Female==1], dat$Help[dat$Female==0])
wilcox.test(dat$RoleM[dat$Female==1], dat$RoleM[dat$Female==0]) #significant
wilcox.test(dat$PriorExp[dat$Female==1], dat$PriorExp[dat$Female==0])
wilcox.test(dat$Childhood[dat$Female==1], dat$Childhood[dat$Female==0])
#significant
wilcox.test(dat$InformalExp[dat$Female==1], dat$InformalExp[dat$Female==0])
wilcox.test(as.integer(as.character(dat$Fam[dat$Female==1])),
as.integer(as.character(dat$Fam[dat$Female==0])))
```

Appendix C: Engineering Student Interview Protocols

All interviews, pre- and post-program, were semi-structured and as such, the interview questions served as a guide.

Pre-program interview questions:

1. Why did you volunteer to work with the elementary students?
2. How would you describe an engineer?
3. How much do you like doing engineering projects?
4. In general, how useful is learning engineering for you?
5. How important is it to you to be good at engineering?
6. How important is it to you that others think you are good at engineering?
7. Do you identify as an engineer?
8. How good at engineering are you?
9. If you were to list all the students in your program from the worst to the best at engineering, where would you put yourself?
10. Compared to most other school subjects, how good are you at engineering?
11. How well do you expect to do in this engineering course?
12. How good would you be at learning something new in engineering?
13. What does being a role model mean to you?
14. What do you perceive as the positive and negatives of being a role model?
15. Based on your observations and experiences, what do you have to offer school children?

Post-program:

1. How did you feel about your experience working with the elementary students?
2. How do you think they perceived you?
3. Did you feel like a role model?
4. Can you describe a notable experience you had in being a role model?
5. Thinking about the elementary students in their role as your clients, did they feel like real clients?

6. How did this relationship to design and build for a client impact your experience with the course?
7. What did you think about the goal of this project—to have the robots dance together instead of having a competition for the robots to compete in?
8. Do you identify as an engineer?
9. How good at engineering are you?
10. How well do you feel you did in this course?
11. In general, how would you describe your experience with this course? Probe: What did you like most? Least?
12. What did you learn from your experiences in this course?
13. How did your experience in this course compare to your other courses?
14. Do you have any feedback about how to make this course better?

Appendix D: Elementary Student Interview Protocols

All interviews, pre- and post-program, were semi-structured and as such, the interview questions served as a guide.

Pre-program interview questions:

1. Why did you sign up for this program and what do you hope to get out of it?
2. Do you know any engineers? If so, who are they?
3. How would you describe an engineer?
4. How much do you like doing engineering projects?
5. Some things that you learn in school help you do things better outside of class, that is, they are useful. For example, learning about plants might help you grow a garden. In general, how useful is learning engineering?
6. How important is it to you to be good at engineering?
7. How important is it to you that others think you are good at engineering?
8. Do you think that you are an engineer?
9. How good at engineering are you?
10. If you were to list all the students in your class from the worst to the best at engineering, where would you put yourself?
11. Some kids are better at one subject than in another. For example, you might be better at math than at reading. Compared to most of your other school subjects, how good are you at engineering?
12. How well do you expect to do in this engineering program?
13. Do you think you might study engineering in college?
14. Do you think you might work as an engineer when you grow up?
15. What makes a person your role model?
16. What do you want and not want to see in an engineer role model?
17. The project you are participating in brings in engineer role models for students. What suggestions do you have for those of us trying to match you up with an engineer role model?

Post-program interview questions:

1. How did you feel about working with the freshman engineers (*include names*)?
2. How did you feel about working with the SWE engineers (*include names*)?
3. Would you consider any or all to be role models for you? Why?
4. How do you feel about the goal of this project—to have the robots dance together, instead of having a competition for the robots to compete in?
5. Do you think that you are an engineer?
6. How good at engineering are you?
7. How well do you feel you performed in this engineering arts program?
8. How likely it is that you will study engineering or work as an engineer?
9. In general, how would you describe your experience with this program? Probe: What did you like most? Least?
10. What did you learn from your experiences in this program?
11. Would you like to participate in a similar program again in the future?
12. Do you have any feedback about how to make this program better?