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The Importance of Collaborative Design for Narrowing the Gender Gap in Engineering: An Analysis of Engineering Identity Development in Elementary Students

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Keywords

collaboration, elementary school, engineering identity, gender gap, role models, shared goals

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The Importance of Collaborative Design for Narrowing the Gender Gap in Engineering: An Analysis of Engineering Identity Development in Elementary Students

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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 collaborative engineering design on the development of engineering identities in elementary-school students and compared the findings across gender. We focused on three tiers of collaboration embedded into the engineering design process: 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 come together for a coordinated dance performance. We used ethnographic methods, including pre- and post-program 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 toward a shared goal over 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 in identity development in girls and boys. Our results suggest that engineering design programs 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 et al., 2010; Régner et al., 2014). A gender achievement gap, however, remains in advanced high school STEM courses, with fewer girls taking advanced placement science and mathematics, a trend which continues into college and the workforce. In addition, girls still

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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 (Hill et al., 2010). Still, women earn only 20% of engineering undergraduate degrees in the USA 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.

A compelling explanation for the persistent gender gap in engineering and other STEM disciplines is that they are traditionally framed in ways that exclude women and people of color; the culture and practices of engineering must be changed to include a variety of identities (Brickhouse, 2001; Brickhouse et al., 2000; Brotman & Moore, 2008; Busch-Vishniac & Jarosz, 2004; Carlone & Johnson, 2007; Riley et al., 2009). Mainstream science and engineering are commonly viewed as objective, competitive, and impersonal, qualities associated with a masculine identity that can be alienating or off-putting to girls (Brickhouse, 2001; Brickhouse et al., 2000; Riley et al., 2009). Students are often confused or ignorant about STEM careers, holding limited and stereotypical views of scientists and engineers (Christidou, 2011; Kekelis & Joyce, 2014). Students, regardless of their own race and gender, tend to view scientists as middle-aged, white, eccentric, and male (Finson, 2003) and engineers as “nerdy, white, alone, and male” (Kekelis & Joyce, 2014, p. 34). Even when girls and students of color report enjoying STEM, they often have difficulties seeing themselves as STEM people (Archer et al., 2010; Herrera et al., 2012; Sorge et al., 2000). According to Archer et al. (2010), “A science identity as it is popularly configured appears unintelligible for some children and young people due to its dominant gendered, raced, and classed configuration” (p. 637). As a result, 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 they *identify with the domain* (Brickhouse et al., 2000). Whether or not students develop identities in domains such as engineering has been shown to substantially impact their future educational and career choices (Tai et al., 2006; Vossoughi & Bevan, 2014).

Although efforts have been made to address the engineering gender gap, research makes it clear that targeting students at the college level to increase diversity in engineering is not sufficient (Busch-Vishniac & Jarosz, 2004). Gendered attitudes toward mathematics, a discipline integrally related to engineering, are evident by kindergarten (Ceci et al., 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 et al., 2017). In comparison to their male counterparts, elementary-aged girls tend to think that engineering is more difficult and are less encouraged by their parents to pursue engineering as a career (Kekelis & Joyce, 2014). Indeed, research shows that sense of self in engineering is solidified in elementary school (Correll, 2001). By eighth grade, students who expect to enter science-related careers as adults are three times more likely to become engineers than students who do not expect to do so (Tai et al., 2006). In addition, high school students with higher self-assessments of mathematics ability, who tend to be male, are more likely to enroll in high school calculus courses and subsequently major in STEM fields in college, even after controlling for actual mathematics ability (Correll, 2001). Such findings suggest that understanding and promoting the construction of a domain-specific *identity* early on in a student’s education are vital for diversifying the field of engineering.

Our research contributes to narrowing the gender gap in engineering by investigating a partnership between undergraduate engineering students and elementary students, who are at a crucial age for developing an engineering identity (Bian et al., 2017; Correll, 2001). The partnership was designed to shift the focus away from helping diverse groups *fit* into the current engineering culture and toward changing the culture to better reflect a broader range of views and experiences by emphasizing the social side of engineering (Calabrese Barton & Brickhouse, 2006; Riley et al., 2009). More concretely, we explored the role of *collaborative engineering design* in the formation of elementary students’ engineering identities. The 10-week partnership program facilitated collaborative engineering design through three tiers of collaboration embedded into the engineering design process. 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 the robots together to perform a coordinated dance. In short, we investigated how elementary students’ engineering identities were influenced by the culture and practice of collaborative engineering design defined at three levels: working with their peers, working with undergraduate engineering role models, and working on projects toward a shared goal (the final robot dance).

We organized our study around the following two research questions: (1) How did elementary students’ engineering identities change over time? (2) What role did collaborative engineering design (i.e., working with peers, working with undergraduate role models, and working toward a shared goal) play in the development of engineering identities? To address these questions, we qualitatively analyzed data collected from elementary student participants throughout the course of the partnership program first as a collective and then again by gender. Our findings have implications for research and practice by presenting a novel program that bridged undergraduate and elementary engineering education, contributing to the field of newly emerging identity research on girls in engineering, and providing insight into the structures that support underrepresented groups in engineering programs.

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Situating Our Study in the Literature

As introduced above, currently in the USA only 20% of engineering undergraduates are women and less than 17% are people of color (NSF, 2015). This lack of diversity in engineering is, in part, a consequence of the way the discipline has been traditionally presented to students—as highly technical and detached from everyday social contexts (Busch-Vishniac & Jarosz, 2004; Johnson et al., 2015). Although students may learn about environmental and economic issues in engineering courses, equity, social justice, and community concerns are not typically covered (Johnson et al., 2015). Such absences pose a substantive barrier, as many women and students of color have found social relevance and community contributions to be powerful motivators for pursuing STEM degrees (Hill et al., 2010; Johnson, 2012). The presence of few women and students of color is also, in part, a result of unwelcoming environments, lack of mentorship, and an emphasis on competition over collaboration when entering engineering majors (Busch-Vishniac & Jarosz, 2004). Engineering education must change so that all students are able to identify with the discipline and to see themselves as successful engineers (Carlone & Johnson, 2007; Herrera et al., 2012).

While these barriers to participation and success are significant, researchers have identified approaches and program structures that can shift the culture of engineering and encourage identification with the domain by women and people of color. Below, we review research on the supportive elements of collaboration and role models in the context of other elementary engineering and STEM education programs. We then move to present our program's approach, specifying how it uniquely contributes to the current literature.

Collaboration

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 than men (Busch-Vishniac & Jarosz, 2004; Goodman et al., 2002; Shapiro & Williams, 2012). Girls and women often feel intimidated and take a back-seat role in competitive, quick-response, weed-out types of environments (Carlone & Johnson, 2007).

In contrast, more collaborative approaches have been found to help retain girls in male-dominated subjects, such as computer science, engineering, and physics (Weisul, 2017). There exists a large body of research that shows collaboration can be used to engage a more diverse population in engineering and to help individuals construct engineering identities (Busch-Vishniac & Jarosz, 2004; Cunningham & Lachapelle, 2014; Goodman et al., 2002; Menekse et al., 2017; Pattison et al., 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 tend to equate collaboration solely with the element of teamwork and thus 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 effect of collaboration in informal engineering environments on students' engineering identities without considering the value of shared goals (Wang, 2013). Research has shown that Maker Faires, which showcase people's creations, can increase participation by offering a non-competitive alternative to science fairs and robotics competitions (Wittemyer et al., 2014).

Role Models

Female mentors and role models have also been proposed as a solution to encourage more girls to pursue STEM disciplines such as engineering and to provide a buffer against discrimination or stereotypes (Alper, 2013; Beeton et al., 2012; Farland-Smith, 2009; Munley & Rossiter, 2013; Sorge et al., 2000; Wittemyer et al., 2014). 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). 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. Role models benefit girls personally and professionally, promoting creativity and problem solving, and improving recruitment and retention for women in STEM fields (Farland-Smith, 2009; Wittemyer et al., 2014). Female mentors, in particular, can help girls and women feel more comfortable and persist in male-dominated fields such as engineering. Techbridge, an initiative in partnership with the Society of Women Engineers (SWE) that works with over 5,000 girls in K–12 after-school programs, provides a powerful example: Findings highlight the importance of the SWE mentors in breaking down stereotypes, increasing self-confidence, building personal connections, and using the engineering design process (Kekelis & Joyce, 2014).

To clarify, interacting with professional women in STEM can help to encourage girls to pursue these disciplines *if* such role models are carefully selected. In a qualitative study with 13 eighth-grade girls, 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 et al., 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.

There is additional evidence of the value of role models who are close in age to the youth they are asked to support (Munley & Rossiter, 2013). Older students, program alumni, and undergraduate volunteers can serve an invaluable role as "near peer" mentors. Rees and colleagues (2015) described the importance of near peer mentors in their university–community partnership makerspace: Mentors acted as "ambassadors" for participation in STEM fields. Through discussions with college students, youth learned about the culture of these fields and imagined themselves participating in them in their future.

Contributing to the Literature

While there is widespread consensus that a diverse engineering workforce is needed, most approaches merely treat symptoms of a larger problem rather than fix underlying issues (Busch-Vishniac & Jarosz, 2004). In order to make lasting improvements, new types of approaches must be explored to deconstruct and systematically address the larger problem concerning the lack of women and people of color in engineering. Much of the research conducted has focused on engineering in middle and high school as opposed to engineering in elementary school, and many of these studies have not considered differences across gender. In addition, while research concerning engineering does include students working in collaboration with their peers, the end goal of these projects is usually one that revolves around a competition, adhering to qualities that females and underrepresented minorities struggle with in engineering (Busch-Vishniac & Jarosz, 2004; Goodman et al., 2002; Shapiro & Williams, 2012).

To fill gaps in the research literature, we investigated how a community-based program intentionally built on inclusive design principles supported elementary students' development of engineering identities. As recommended by other scholars (Calabrese Barton et al., 2016; Holbert, 2016; Tan & Faircloth, 2016), we attempted to bring STEM activities to a community space that was already welcoming and familiar to underrepresented groups (Calabrese Barton et al., 2016; Holbert, 2016; Tan & Faircloth, 2016). While community is considered an integral part of informal STEM spaces, educators have still reported that "creating a sense of community is a central and on-going challenge" (Rees et al., 2015, p. 10). In contrast to previous research on engineering outreach, we focused on elementary students, an often overlooked age group that is of vital importance as girls start to view boys as more capable in engineering early on (Bian et al., 2017; Correll, 2001). We explored the impact of a shared end goal, which is atypical of most competition-based engineering projects, and closely analyzed the influence of near peer role models. Undergraduate engineering majors, including a large number of women, served as "professional engineers" for the elementary students to both work with and emulate. Taken together, our study contributes to the research by providing insight into how informal and multi-tiered collaborative engineering design programs influence elementary girls' and boys' identities as engineers.

Theoretical Framework

Our study, grounded in feminism as a movement toward social justice, explores the potential of collaborative engineering design to help more girls develop identities as engineers by placing value on the social nature of engineering. Prominent feminist scholars, such as Fox Keller and Scharff-Goldhaber (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 several 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, U.S. engineering programs currently foster a culture of disengagement with public welfare concerns (Ing et al., 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 suppress 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 away from helping girls (and other diverse groups) adapt to the current engineering culture and toward changing the culture to better reflect a broader range of views and experiences (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 toward a shared goal is also important and deserves recognition and value.

The goal of our partnership program was to help more students, particularly more girls, develop identities as engineers by placing value on the social side of engineering. We attempted to accomplish this goal by grounding our curriculum in collaborative engineering design. Engineering design frameworks have been gaining traction in both formal and informal educational settings in recent years (e.g., Engineering is Elementary; see Cunningham et al., 2018), corresponding to the introduction of engineering disciplinary knowledge and the engineering design process in the K–12 Next Generation Science Standards (NGSS) (Quinn & Bell, 2013). The cyclical and systematic nature of the engineering design process (i.e., identify the problem, develop possible solutions, make a model prototype, and evaluate and refine the prototype) models the work of professional engineers and ensures that students consider the end user's needs and work within a set of realistic constraints (Dym et al., 2005). According to Quinn and Bell (2013), engineering design was included in the NGSS as "a deliberate decision to broaden the curriculum, both because engagement in design activities can support student learning and interest in science and because knowledge about the engineering design cycle is itself something that all students can benefit from" (p. 31). Beyond engineering design, we carefully developed our curriculum to be highly collaborative. The elementary students in our study came together regularly with undergraduate engineers to share knowledge and experiences related to engineering. This community was collaborative not only because elementary students worked with teams of peers and role models, but because students worked toward a shared end goal of a coordinated robot dance performance.

A significant body of work has focused on identities-in-practice, which acknowledges that identities develop as students engage in communities of practice (Tan & Calabrese Barton, 2008; Tan et al., 2013; Tonso, 2006). And in an ethnographic study of undergraduate engineering students, Tonso (2006) referred to identity production as a combination of viewing oneself as an engineer and being viewed by others as an engineer. 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 California with students from diverse ethnicities, our reach extends beyond gender, although the 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 in California and a nearby research university. 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 (first-year) mechanical engineering design course at the nearby university (*freshman engineers*) and volunteers from the university chapter of the SWE (*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 of approximately 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, one to two freshman engineers, and one to two SWE engineers, though the junior engineers met with the freshman engineers and SWE engineers separately during alternate weeks. Figure 1 presents an overview of the program and Figure 2 illustrates the relationships among the junior engineers, freshman engineers, and SWE engineers.

The junior engineers were expected to complete two tasks to contribute to the final robot. First, the junior engineers produced preliminary sketches for how the robots would look and dance and worked with their freshman engineer teammates 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 teammates; for example, the 3D-printed head of a unicorn robot, the light-up plush body (sewn with e-textiles) for a whale robot, or the 3D-printed head of a wolf with light-up LED eyes. The freshman engineers were responsible for creating the remainder of the robot for credit in their university course. The undergraduate course was taught by a professor of mechanical engineering, an author of this paper. 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 teammates for three design team meetings, spread throughout the quarter, to discuss and revise the designs for the dancing robots and to integrate their pieces for the final product. The SWE engineer teammates were not part of these meetings. The first and third design team meetings occurred at the elementary school while the second took place on the university campus and included a tour of the mechanical engineering labs. During the interim weeks, the junior engineers worked on their contribution to the robot (e.g., the 3D-printed head of a unicorn robot, the light-up body of a whale robot, the 3D-printed head of a wolf with LED eyes) at the elementary school. This elementary-school portion of the program during the interim weeks was led by the SWE engineers, with help from the lead author of this paper, an engineer and educational researcher. All members of a given team met once, during week 10 of the program, for the final robot dance performance.

Participants

For this study, we focused on 14 of the 42 junior engineers enrolled in the after-school engineering program. Participants 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

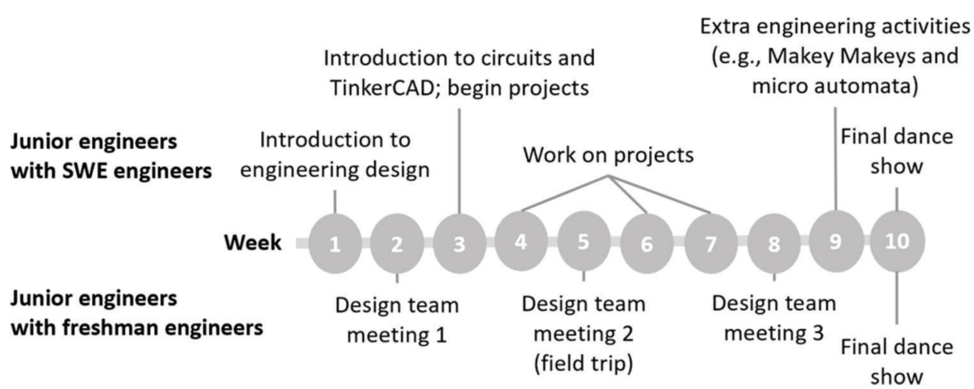

Figure 1. Timeline of the 10-week Engineering Arts program.

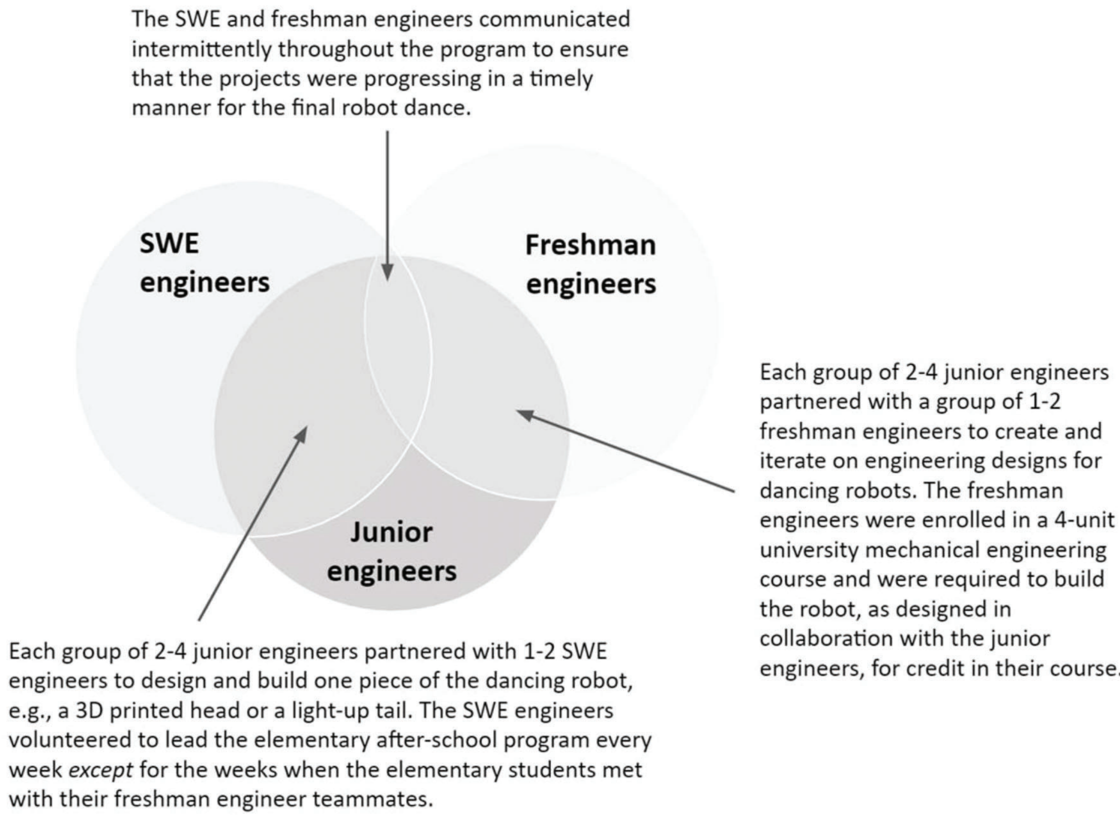

Figure 2. Overview of relationships among the junior engineers, freshman engineers, and SWE engineers.

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; 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.

Data Collection

Data were collected for this study over a period of 10 weeks in the spring quarter of 2018. The full dataset 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 (see Table 1).

The pre-program interviews were conducted individually 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. With the goals of the paper in mind, semi-structured interviews were conducted to ensure that both research questions would be answered while still giving participants a voice. The guiding questions for the pre- and post-program interviews used for this analysis are shown in Table 2.

Video data were collected for two teams (four elementary students and four undergraduate engineers) during eight of the ten weekly sessions. These two teams were selected because they were the only ones 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 program; thus, we were unable to track our two focal teams. 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 freshman engineers and the first project session with SWE engineers. We explored how the elementary students interacted with one another and their undergraduate engineering teammates, as well as the way 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 ideas for the structure and movement of the robot 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.

Table 1
Participants and data collection.

Data collected	Description of elementary students in research study	Description of undergraduate role models in research study
Pre-program interviews, post-program interviews, and collection of student work	14 junior engineers • Gender: 6 girls and 8 boys • Racial/ethnic background: 4 Latinx, 5 European Americans, 4 Asian Americans, and 1 African American	Not applicable
Video recordings	4 junior engineers (subset of the 14 above) • Gender: 2 girls and 2 boys • Racial/ethnic background: 1 European American and 3 Asian Americans	2 freshman engineers • Gender: 1 woman and 1 man • Racial/ethnic background: 1 European American and 1 Latinx 2 SWE engineers • Gender: 2 women • Racial/ethnic background: 2 European Americans

Table 2
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?

Analysis

Our qualitative analysis of data proceeded in two phases. First, the interview and video data were transcribed, 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., describe self as an engineer, confidence in engineering ability, growth mindset, being thought of by others as an engineer) and collaborative engineering design (i.e., 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 3.

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.

Table 3
Codes used for qualitative analyses of interview data.

Themes	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
Collaborative engineering design	Influence from peers	Students describe a peer as one of the reasons they joined and/or engaged in the engineering design 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. Alternatively, students express that they engaged in the program because of (c) their general experience collaborating with the undergraduate engineers
	Working toward a shared goal	Students describe interest in working on a collaborative engineering design project with their peers and/or the undergraduate engineers

That is, we sought to determine the extent to which students viewed themselves and 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 collaborative engineering design in the students' developing engineering identities, we analyzed interview responses related to the collaborative nature of the engineering design work 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 for participating in the program and definitions of role models. We also examined the intersection of collaborative engineering design and engineering identity codes to determine whether the collaborative 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 collaborative engineering design 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.

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 collaborative engineering design in the development of engineering identities.

Elementary Students' Developing Engineering Identities

To answer our first research question, we compared the ways elementary students discussed themselves in relation to engineering across their pre- and post-program interviews. 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, which was likely a product of the students having self-selected into the Engineering Arts 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 3).

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 that which he did have 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). 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."

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 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 program "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.

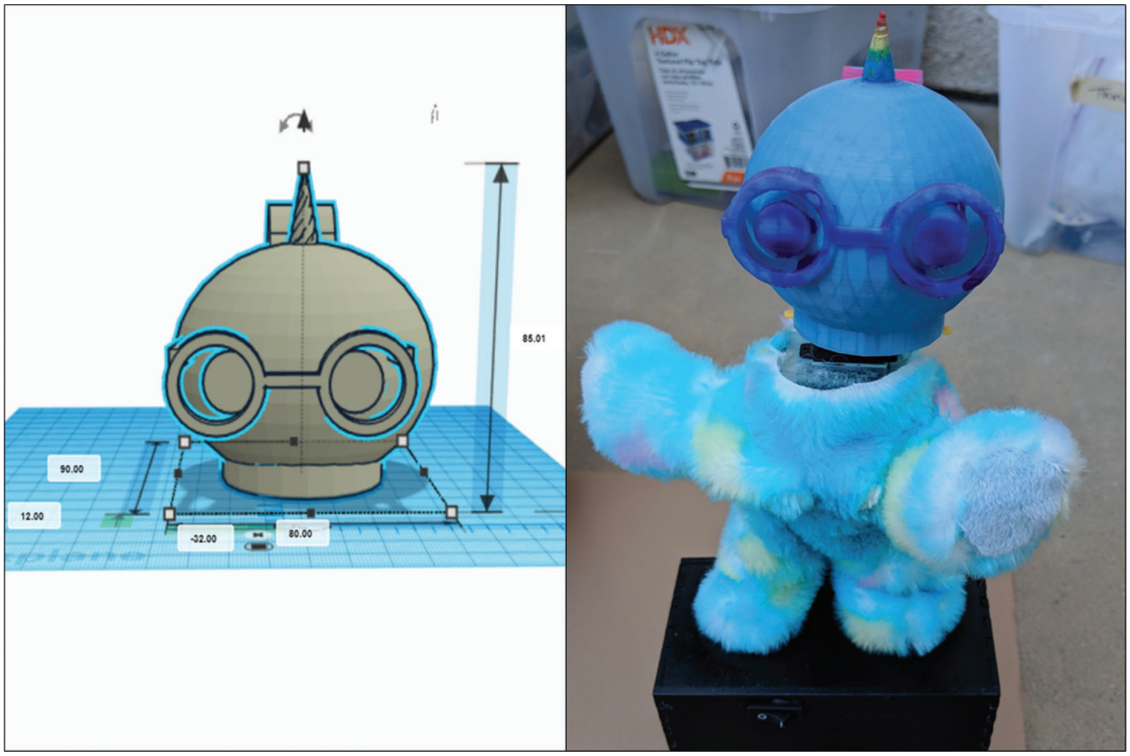

Figure 3. The 3D design for Sadie's robot head in TinkerCAD (left) and the completed robot (right).

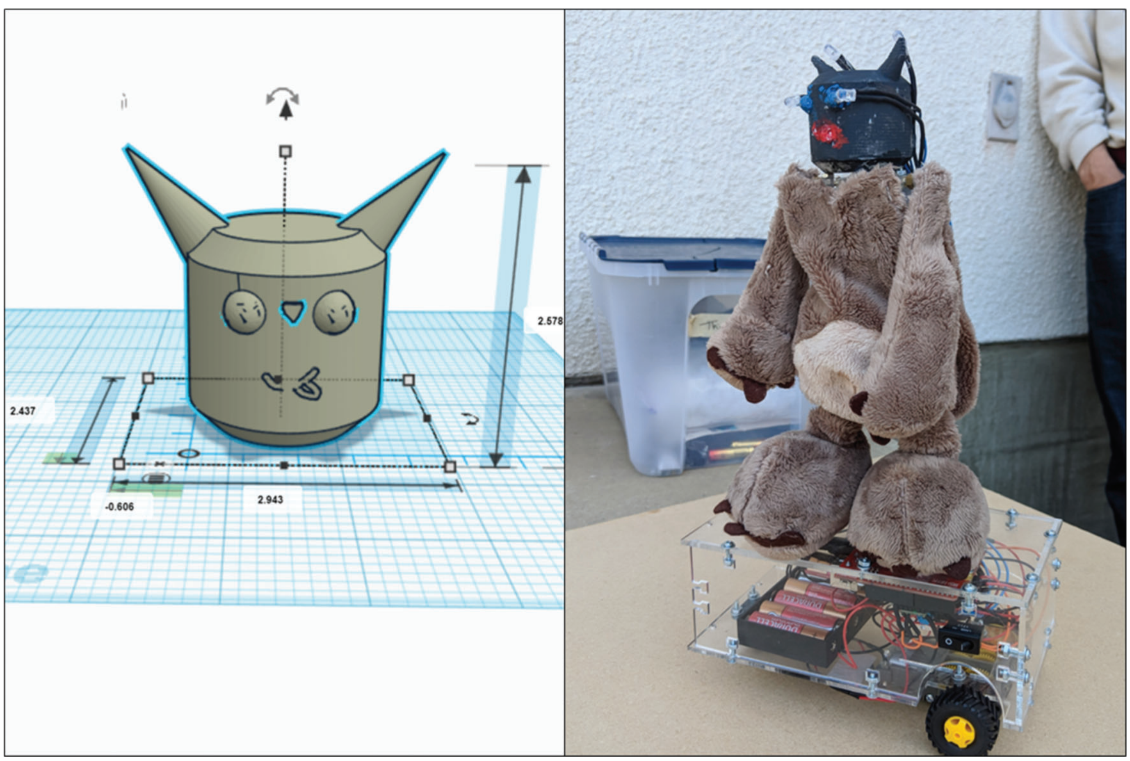

Figure 4. The 3D design for James' robot head in TinkerCAD (left) and the completed robot (right).

The Role of Collaborative Engineering Design in the Development of Engineering Identities

To answer our second research question, we analyzed students' interview responses related to the collaborative engineering design process established in the program via peer groups, role models, and shared goals (i.e., the final robot group dance). This collaborative engineering design process was highly influential in engaging the students in engineering and contributed to the development of their engineering identities. While all students benefited from this design 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 the following: "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 elementary teammate: "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."

Though students, aside from Javier, did not mention 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. Sadie explained that she was not initially interested in engineering and 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 teammates, both the freshman and SWE engineers, as role models. In expressing their reasons, most of the 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 undergraduate engineer teammates, 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 teammates, 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. This was evident as early as the first design team meeting: After brainstorming ideas for their robots, Sahira, her elementary teammate Deepti, 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 5). 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

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

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 teammate 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 undergraduate 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."

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 teammates, Bernardo, as a role model because of how helpful he was in building the robot to Ethan's specifications and designs. 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 came from the first team meeting. There was sustained back-and-forth dialogue around the robot design between the elementary students, Ethan and Aman, and the undergraduate engineers, Bernardo and Gabriella. 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 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?

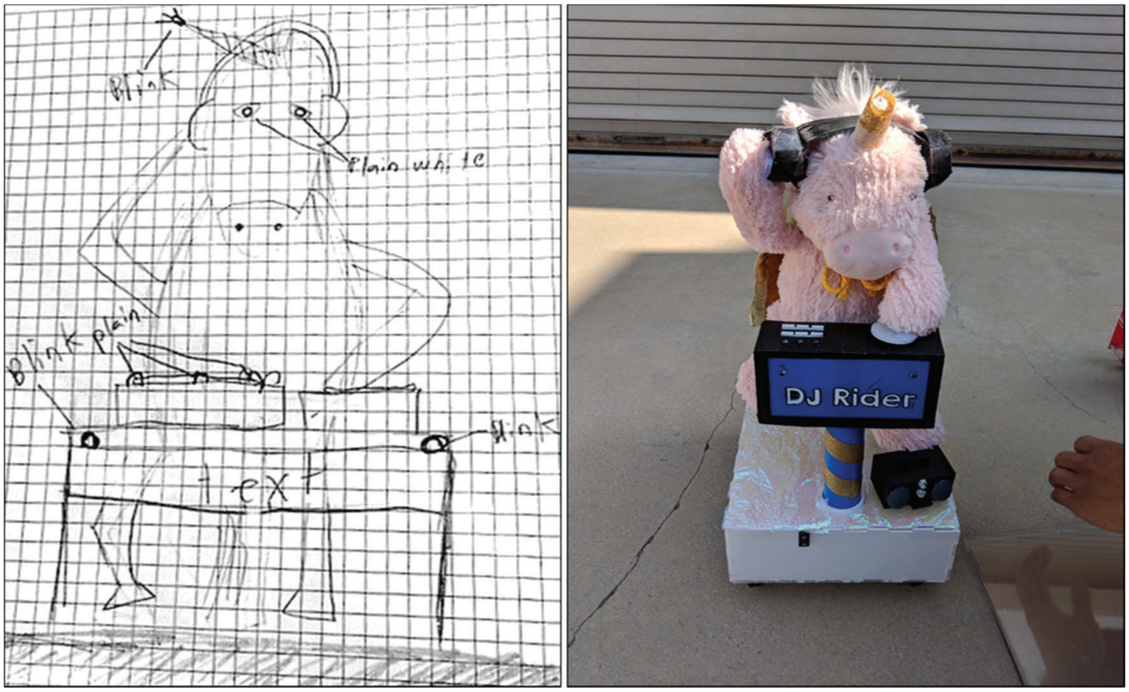

Figure 6. Ethan's DJ unicorn robot engineering sketch from the first design team meeting (left) and the completed robot (right).

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 toward 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."

Working toward a shared goal

As we have described throughout the paper, the 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 and Conclusions

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 design 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, six girls and eight boys, as they moved through a 10-week, collaborative engineering design program run in partnership with engineering students from a nearby university, who served as near peer role models. The majority of elementary students began the program with relatively low levels of confidence in their engineering abilities. However, as a result of their successful engineering projects in collaboration with supportive peers and mentors, by the end of the program all students closely identified with engineering, feeling more capable and confident in their skills. The projects were carefully designed to be sufficiently complex to allow the elementary students to master each stage of the engineering design process but also within reach of their abilities, when coupled with support from their peers and mentors, to ensure that all students would experience success. The partnership program facilitated collaborative engineering design through three tiers of collaboration embedded into the process: peer groups, role models, and inter-group collaboration. Below, we discuss the implications of each of our three tiers of collaboration 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. 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 the undergraduate engineers. All students viewed their undergraduate teammates as engineer role models and engaged more in engineering because of the relationships they developed. In line with the research of Buck et al. (2008), 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 undergraduate 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 the girls and over half of the boys in our program preferred working toward the shared goal of a robot flash mob over 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 collaborations in elementary engineering programs.

The results from our study suggest that programs grounded in collaborative engineering design 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 ones, may contribute to the narrowing of the gender gap. However, the conclusions that can be drawn from this study are limited by our sample size and data. While the experiences of six girls and eight boys serve as an important starting point for understanding the effect of collaborative engineering design on students' developing identities as engineers, more work needs to be done. For example, 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 collaborative engineering design on elementary students' developing engineering identities.

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