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Modification and Assessment of a Residential Summer Program for High School Women

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Modification and Assessment of a Residential Summer Program for High School Women

Abstract

The importance of reducing the gender gap in engineering programs by recruiting and retaining female students is well recognized. Although women hold roughly half of all jobs in the United States, only 24% of STEM jobs are occupied by women. The problem is even more pronounced for engineering, where women held about 12% of jobs as of 2013 (Corbett & Hill, 2015). Consequently, interactive, hands-on outreach programs are a common tool used by universities to encourage interest in engineering from K–12 students. Engineering—Get Into Real Learning (E-GIRL) is a week-long, residential summer program offered by Texas Tech University for female high school students. The primary goal of the program is to help participants make informed decisions about engineering majors and careers. To this aim, the purposes of the program are: (1) to offer a platform for female high school students to learn about the various disciplines of engineering offered at Texas Tech University and other universities; (2) to provide a realistic university experience, including coursework, social, and professional development opportunities; and (3) to provide hands-on exposure to a real-world engineering problem. E-GIRL ran for the second time in the summer of 2016, based on the favorable support it received in 2015. Primary components of this year's program were a multidisciplinary group project focused on the theme of CO_2 capture and storage, as well as a series of two-hour classes taught by university faculty and graduate students in the following six engineering disciplines: chemical engineering, civil engineering, environmental engineering, industrial engineering, mechanical engineering, and computer science. This paper presents the multidisciplinary structure of the program and its connection to the project that was assigned to program participants. The curriculum structure, the in-class activities, and the method of delivery for each discipline are explained in depth. The assessment of the program's second year, including comparisons to the results from the first year and modifications to the program based on feedback from previous program participants, are discussed. Assessment was conducted through engineering skills assessment questionnaires, which required students to self-evaluate their competence in 18 skill sets before and after the program. These skill sets are qualities often identified to be important for engineers, and encompass traits associated with problem solving, project management, teamwork, and communication skills. Key results show improved self-assessment for most of the engineering skills after the program. Additionally, the skills that did not show improved self-assessment ratings after the program were consistent throughout both years. Qualitative results show a more matured and complete understanding of engineering and the individual engineering disciplines upon completion of the program. Through oral presentations, participants demonstrated in-depth engagement with the environmental conservation theme of the project. The environmental conservation theme is consistent with the participants' aspirations for considering an engineering career and championing sustainability, which was highlighted by program participants in 2015 as a desired additional focus of the program. Overall, the program provided an opportunity for participants to experience the multidisciplinary nature of engineering, aided participants' understanding of the roles of individual engineering disciplines, and furnished a realistic preview of student life in a university.

Keywords

women in engineering, outreach, multidisciplinary, cooperative learning

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Abstract

The importance of reducing the gender gap in engineering programs by recruiting and retaining female students is well recognized. Although women hold roughly half of all jobs in the United States, only 24% of STEM jobs are occupied by women. The problem is even more pronounced for engineering, where women held about 12% of jobs as of 2013 (Corbett & Hill, 2015). Consequently, interactive, hands-on outreach programs are a common tool used by universities to encourage interest in engineering from K–12 students. Engineering—Get Into Real Learning (E-GIRL) is a week-long, residential summer program offered by Texas Tech University for female high school students. The primary goal of the program is to help participants make informed decisions about engineering majors and careers. To this aim, the purposes of the program are: (1) to offer a platform for female high school students to learn about the various disciplines of engineering offered at Texas Tech University and other universities; (2) to provide a realistic university experience, including coursework, social, and professional development opportunities; and (3) to provide hands-on exposure to a real-world engineering problem. E-GIRL ran for the second time in the summer of 2016, based on the favorable support it received in 2015. Primary components of this year's program were a multidisciplinary group project focused on the theme of CO_2 capture and storage, as well as a series of two-hour classes taught by university faculty and graduate students in the following six engineering disciplines: chemical engineering, civil engineering, environmental engineering, industrial engineering, mechanical engineering, and computer science. This paper presents the multidisciplinary structure of the program and its connection to the project that was assigned to program participants. The curriculum structure, the in-class activities, and the method of delivery for each discipline are explained in depth. The assessment of the program's second year, including comparisons to the results from the first year and modifications to the program based on feedback from previous program participants, are discussed. Assessment was conducted through engineering skills assessment questionnaires, which required students to self-evaluate their competence in 18 skill sets before and after the program. These skill sets are qualities often identified to be important for engineers, and encompass traits associated with problem solving, project management, teamwork, and communication skills. Key results show improved self-assessment for most of the engineering skills after the program. Additionally, the skills that did not show improved self-assessment ratings after the program were consistent throughout both years. Qualitative results show a more matured and complete understanding of engineering and the individual engineering disciplines upon completion of the program. Through oral presentations, participants demonstrated in-depth engagement with the environmental conservation theme of the project. The environmental conservation theme is consistent with the participants' aspirations for considering an engineering career and championing sustainability, which was highlighted by program participants in 2015 as a desired additional focus of the program. Overall, the program provided an opportunity for participants to experience the multidisciplinary nature of engineering, aided participants' understanding of the roles of individual engineering disciplines, and furnished a realistic preview of student life in a university.

Keywords: women in engineering, outreach, multidisciplinary, cooperative learning

Introduction

The recruitment and retention of women in engineering is an issue that is considered important by both academics and practitioners (National Research Council, 1991), as engineering problems are often multidisciplinary challenges that require input from various engineering faculties and benefit from a diverse set of viewpoints (Wilson, 1992). It is therefore concerning to note that the participation of women in STEM education (National Science Foundation, 2000; Education, 2014), and subsequently in engineering-led employment, is subpar to that of men (Beede, Julian, Langdon, McKittrick, Khan, & Doms,2011; Wang & Degol, 2016). The underrepresentation of women in STEM education indicates a pressing need to identify and address potential barriers and to design mechanisms specifically focused on attracting and retaining women in engineering degrees and careers.

Although a recent study shows that the number of women in science and engineering is growing, men continue to outnumber women, especially at the upper levels of these professions (Hill, Corbett, & St. Rose, 2010). Thom, Pickering and Thompson conducted a study on recruiting models and concluded that the traditional recruiting model ignores the internal needs of young women who are conscious of self-image and self-worth and who worry that women in technical careers are perceived as less feminine (Thom, Pickering, & Thompson, 2002). As early as elementary school, boys typically possess more interest in studying science than girls. By middle school, girls' interest in science tends to decline, and this decline may persist through high school (Jones, Howe, & Rua, 2000). Young women may also fear failure and assume that males have superior technical knowledge. Further, a perceived lack of support, communication, and camaraderie may deter young women from pursuing technical careers. Thom and Thompson suggest that to interest young women in technical careers, an atmosphere of mutual assistance and effective communication may be required (Thom et al., 2002).

Interestingly, in elementary, middle, and high school, girls and boys take math and science courses in roughly equal numbers, and about as many girls as boys leave high school prepared to pursue science and engineering majors in college. By graduation, however, men outnumber women in nearly every science and engineering field. The difference is dramatic in the latter, with women earning only 20% of bachelor's degrees (Hill et al., 2010). Hill, Corbett, and Rose conclude that while biological gender differences may play a role, these differences are clearly not the whole story (Hill et al., 2010). They suggest that girls' achievements and interest in math and science are shaped by the environment around them. For example, a simple training course can dramatically improve spatial skills, which are generally considered important in engineering and for which men consistently outperform women. So, girls who are offered spatial training or similar preparatory courses may experience increased confidence and skill, and be more likely to consider a future in a STEM field. The researchers also call for institutions to communicate that girls and boys are equally capable of achievement in math and science, as well as encourage high school girls to take calculus, physics, chemistry, computer science, and engineering classes when available (Hill et al., 2010).

The purpose of Engineering—Get Into Real Learning (E-GIRL) is to expose female high school students to the vast array of engineering disciplines needed to solve challenges in the oil and gas industry. Students are often unable to articulate the differences among various engineering disciplines, and are even less certain about how the disciplines work together to accomplish projects. As such, the participants of the E-GIRL program were provided a classroom experience designed to teach them about engineering disciplines in the context of an industry (oil and gas) challenge, specifically related to CO_2 capture. The participants then selected a discipline/role to experience during the group project on CO_2 capture. Through this experience, it was expected that participants would gain a better understanding of the activities an engineer may conduct in her career, as well as an engineering college curriculum.

Existing outreach efforts to expose students to engineering at Texas Tech University (TTU) include three robotics competitions: Get Excited About Robotics (GEAR) for elementary and middle school students, FIRST Tech Challenge and FIRST Robotics Competition for students in Grades 6–12, and West Texas Best Robotics for students in Grades K–12. These robotics competitions are quite popular with several thousand students competing. Additionally, TTU student organizations also sponsor one-day outreach events. For example, the Texas Tech Society of Women Engineers offers Catch the Engineering Bug in the fall and Night at the Science Spectrum in the spring. These events are targeted at females in middle and high school, and include short activities that introduce them to several engineering disciplines. The last offering of Catch the Engineering Bug had nearly 200 girls signed up to learn about engineering.

More broadly, in the state of Texas, one notable effort to introduce students to engineering is the Texas Science, Technology, Engineering, and Mathematics (T-STEM) Academy for students in Grades 6–12. A total of 121 academies exist, 22 of which were chartered in the 2016–2017 school year. At the middle school level, students take three years of STEM electives, while at the high school level four years of STEM electives are taken. The curriculum must be project- and problem-based with extracurricular STEM activities, field experiences, clubs, and competitions. It is optional for students to enroll in the T-STEM academy; for example, 70 of New Deal's 200 high school students opted to join the T-STEM Academy.

Another option for schools is to implement the Project Lead the Way curriculum (www.pltw.org). Project Lead the Way has prepared curriculum for Grades K–12 in three main subject areas, such as computer science, engineering, and biomedical science. In addition, teacher training is available. At the high school level, schools may choose to implement one or more of the three subject areas. Several schools in the independent school districts of West Texas offer Project Lead the Way curriculum including Amarillo (engineering), Pampa (engineering), New Deal (engineering), and Lubbock (engineering, biomedical science).

Since engineering is still optional in Texas schools, and underrepresented females are not specifically recruited for engineering programs, more programs are still needed to be sure that as many K–12 students as possible get a chance to learn about engineering. Indeed, E-GIRL stands out as a balanced effort to introduce girls to engineering with a concerted effort to build a learning community during the week of activities.

In this paper, we first begin by discussing the structure of the program and providing a description of the activities for each of the six engineering disciplines. Next, participant demographics are provided, along with pertinent information related to students' interest in pursuing an engineering career prior to starting the program. The salient results from our study are then discussed and interpreted in the context of women's participation in engineering, followed by our concluding remarks.

Program Structure

E-GIRL is structured as a week-long, residential outreach program. The program was envisaged as a platform to disseminate information about engineering disciplines through a multidisciplinary project modeled after a real-world problem. The multidisciplinary engineering challenge combined discipline-specific projects from computer science, mechanical, civil, environmental, chemical, and industrial engineering. Projects were selected according to a unifying, underlying theme; for 2016, this theme was CO_2 capture, in contrast to the 2015 theme based on hydraulic fracturing (Monaco, Cloutier, Yew, Brunchett, Christenson, & Morse, 2016). Throughout the week, teams of program participants worked together to complete a major project (in this case, the design of a CO_2 capture facility) where each group member played the role of a specific kind of engineer. At the end of the week, groups presented their designs and were able to practice proper and clear communication of technical knowledge, which is required for a successful engineering career. Students also attended classes and participated in campus tours, recreational activities, and professional development activities. Table 1 outlines the day-to-day structure of the program. Any space designated as "Free" indicates that students had the option of choosing how to spend their time (preparing for the next day's classes, working on the group project, etc.).

Table 1
E-GIRL program structure.

	Monday	Tuesday	Wednesday	Thursday	Friday
8:30 AM	Intro to Engineering and Project Overview	Industrial Engineering	Environmental Engineering	Q&A with Instructors	Presentation Practice
9:00 AM					
9:30 AM					Presentations
10:00 AM	TTU Presentation				
10:30 AM		Mechanical Engineering	Computer Science	Football Stadium Tour	
11:00 AM	Safety Training				
11:30 AM	Lunch				Awards
12:00 PM				Project Work	
12:30 PM	Surveys and Assessments	Lunch	Lunch		
1:00 PM					
1:30 PM					
2:00 PM	Civil Engineering	Chemical Engineering	Free	Presentation Skills Workshop	
2:30 PM					
3:00 PM					
3:30 PM					
4:00 PM	Team Building	Campus Tour	Career Workshop	Pool	
4:30 PM					
5:00 PM	Dinner				
5:30 PM		Dinner			
6:00 PM	Free		Dinner		
6:30 PM		Free			
7:00 PM	Student Recreation Center		Movie and Game Night	Pizza and Presentation Practice	
7:30 PM					
8:00 PM					
8:30 PM					

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Throughout the week, participants attended classes taught by faculty and graduate students from the six engineering disciplines involved in this program. While the goal was partially to provide students with a realistic college classroom experience, the classes were intended to be highly active. They generally consisted of a short introductory discussion of the concepts involved, followed by an activity allowing students to explore the concepts more deeply or to solve a small, open-ended design challenge. The "hands-on" activities as part of the discipline-specific projects enabled better conceptualization of the ideas being discussed. In an attempt to help students understand the technological background of certain topics, activities were structured a day before the classroom lecture and provided the requisite information that they needed for comprehension. This structuring was part of the flipped classroom paradigm, where students are actively encouraged to be comfortable with concepts before discussing them in a classroom, thus providing an increased level of understanding and confidence and helping assimilation of abstract concepts (Herreid & Schiller, 2013). Moreover, the course material was designed using Bloom's taxonomy in order to provide clarity and reflect the scientific nature of its content (Krathwohl, 2002). As part of the in-class, discipline-specific activity, the students were divided into groups by the instructors and were asked to collaborate with group members concerning the engineering challenge at hand. This grouping was done to emphasize the importance and necessity of teamwork in engineering, where cooperation impacts the productivity and performance of a given team, and also to implement the concept of cooperative learning (Cohen, 1994;Smith, 1995).

Based on feedback collected from program participants, instructors, and counselors during the 2015 program, some changes were made to the 2016 program. The theme for 2016 was CO_2 capture which, apart from being a global problem, was chosen because of its anticipated appeal to potential women engineers. Participation of women in STEM is often motivated by communal projects that yield benefits beyond commercial gains, such as improving the quality of human life (Dickman, Brown, Johnston, & Clark, 2010). Feedback also implied that students most valued the opportunity to experience a variety of engineering disciplines. Accordingly, each discipline was covered during a two-hour class (rather than an 80-minute class, as in the previous year). Making this change allowed students more time to learn about each discipline in-depth, to interact with individual instructors, and to participate in discipline-specific activities. Finally, the disciplines covered in the E-GIRL program changed slightly from 2015 to 2016. Whereas the 2015 program offered petroleum and electrical engineering as two of the disciplines covered, these were replaced with chemical engineering and computer science in 2016 to reflect the interests of program participants (note that computer science was also covered briefly in the 2015 program but was not included as one of the six disciplines). The following sections provide an overview of the material covered and activities completed for each of the six engineering disciplines.

Chemical Engineering

The chemical engineering course focused on the problem of CO_2 emission and its remediation through chemical processes. As part of the chemical engineering activity, participants designed a model CO_2 sequestrations system for enhanced oil recovery. The course introduction began with a discussion of the role of chemical engineering in improving the quality of human life. Subsequent topics included the carbon cycle, chemical processes of CO_2 generation, and a description of technical principles dealing with capture and sequestration/conversion of CO_2.

The discussion of CO_2 capture and sequestration technologies focused on three main technologies: CO_2 scrubbing using absorption, membrane-based gas-selective separation, and adsorption (Global CCS Institute, 2012). The three technologies were described in terms of their chemical operations and machinery to communicate the concepts of flow, pressure, temperature and chemical reaction, and the applied nature of chemical engineering design. Thereafter, the entire process of on-site CO_2 generation and capture was explained followed by a description of the "Enhanced-oil-recovery" (EOR) process using captured CO_2. Considerable emphasis was placed on the task of explaining the EOR process using CO_2 injection, as this formed the central theme of the final hands-on activity.

The chemical engineering activity asked students to design a model CO_2 injection system for enhanced oil recovery (EOR) and combined elements of process design, pressure pumping, reaction kinetics, and effect of pressure and temperature. An acid-base chemical reaction was used to drive CO_2 generation in one part of the experimental setup, which also ensured that the CO_2 flowed under pressure. A separate component of the experimental setup was used to mimic a porous oil-rock formation, which was connected to the upstream supply of the pressurized CO_2 from the reaction in the experiment. The oil from the reservoir was recovered with the progress of the CO_2 injection. The activity was timed from the start of CO_2 generation until the point where the oil flow into the storage reservoir stopped. The amount of oil recovered and the time taken was measured and recorded in a data sheet along with any other observations from the students. Each group was asked to conduct the experiment twice with a different set of conditions each time.

At the end of the activity, the data collected were shared among the groups. Simple questions were then posed based on the available data to engage the students and enable conceptualization of the activity. The students were then asked to brainstorm and come up with simple explanations for these observations.

Civil Engineering

Civil engineering is responsible for the design of the structure and infrastructure that provides access to the carbon capturing and sequestration facility. A presentation was delivered to E-GIRL participants to explain the multiple civil engineering components that would be involved in the project, namely: structural engineering, transportation engineering, and geotechnical engineering. The presentation also provided information on the various industries where demand for civil engineers is high.

After the presentation, E-GIRL participants were introduced to the various civil engineering materials that are commonly used, such as concrete, asphalt, glass, and steel. Material samples were provided to participants so that they could inspect, compare, and contrast the physical properties of each material; for instance, comparing the weight difference between an aluminum rod and a steel rod of similar dimensions, inspecting the material composition of a concrete block, and observing the ductility of metal objects.

A discussion then followed to explain the importance of foundations to support heavy structures on the ground. The concept of engineering stress (defined as the applied load per unit area) was introduced to participants. Participants were provided with materials to perform a simple experiment illustrating the importance of foundations. In the experiment, participants placed a bottle on a tub of dry sand. The bottle's (opened) top was sliced off so that it was supported on its rim, and weights were then placed on the bottom. Participants observed how the bottle sank into the sand and recorded the amount of settlement (the distance that the bottle sank into the sand). The experiment was then repeated. This time, however, a piece of wood was placed on the sand to model a foundation, and the bottle was placed on the piece of wood before weights were added. Through this experiment, participants learned that the distribution of an applied load over a larger area reduces the loading stress, resulting in negligible settlement even when similar loads are applied on the structure (in this case, the bottle was used to model the structure). This simple experiment demonstrated the importance of foundations, and how they allow even weak soil to carry heavy physical loads.

A worksheet containing questions based on the civil engineering materials discussion and the foundations experiment was provided to students to assess their understanding of the topics discussed and to document their observations in their own words.

Computer Science

The computer science topics focused on computational thinking for the data modeling of CO_2 emissions. Computational thinking was described by Jeanette Wing (Wing, 2006) as the thought processes involved in formulating a problem and expressing its solution in a way that a computer, whether human or machine, can carry out. In addition, computational thinking involves the ability to choose abstractions that are appropriate to the problem and solution formulation, such as model choice and algorithm (set of steps) usage. Students were given a background in data modeling that included a short introduction to programming using sequential, conditional, and looping statements, and was intended to familiarize them with algorithm usage. To familiarize them with models, the students were shown raw data and their corresponding representation as decision tree models and linear regression models, demonstrating the different kinds of solutions available based upon model choice.

The computer science activities gave students practice in algorithms and data models. The first activity utilized the CS Unplugged (csunplugged.org) activity of guessing a number. Students represented the process of guessing as a binary tree to show how many guesses it would take to guess a number from zero to seven or from zero to 15. They then ran an MIT Scratch (scratch.mit.edu) program, filling in the values of variables as the program proceeded to guess the number. Activity two had the students modify a Scratch program to play a simpler form of Jeopardy (jeopardy.com) with questions related to CO_2 emissions. The modification the students performed kept the game player from entering an invalid wager, utilizing an if statement and then a looping statement. The final activity utilized raw data to model atmospheric temperature increases through linear regression as adapted from Witt (2013). The raw data consisted of four attributes related to CO_2 level, solar radiation, El Niño, and volcanic activity. The students investigated variable correlation and added one attribute at a time to the linear regression equation to see how each attribute affected the modeling of atmospheric temperature increases.

Environmental Engineering

Water supply is a vital component to CO_2 capture. Adding CO_2 capture to a coal plant substantially increases its water use per watt. The environmental engineering class covered topics related to water quality, water sources, and membrane filtration technologies to provide the necessary water demand for carbon capture applications.

Membrane filtration technology and definitions were introduced to the students, followed by an in-class activity. The in-class activity asked students to (1) compare various membrane technologies (microfiltration, nanofiltration, and reverse osmosis), (2) demonstrate the physical removal of water contaminants (i.e., suspended solids and total dissolved solids), and (3) calculate filter flow rate and flux rate from their individual filter apparatus. Students were then asked to select the membrane technology suitable for carbon storage applications based on a desired water quality.

Industrial Engineering

The theme selected for the industrial engineering workshop was "Green Supply Chain Manufacturing through Lean." The objectives of the session were multifaceted, including an introduction to types of activities performed by industrial engineers, the process of green supply chain and lean manufacturing, and the role of industrial engineering toward a greener organization. The session emphasized that, in addition to an efficient structure, the design of green and efficient supply chains for construction materials, maintenance and operating machinery and supplies, and carbon products is of extreme importance. For this purpose, green strategies followed at the site to ensure an efficient process, of lesser cost, and of higher quality were discussed.

The industrial engineering session also utilized a hands-on activity, which required students to participate in a paper plane manufacturing simulation game. Students were grouped into two teams and each team was instructed to produce the best quality paper planes within the given time. The simulation entailed two rounds; the first used the "batch concept" and ordinary processing, while the second utilized "one-piece flow concept" and many other lean manufacturing tools to demonstrate an efficient process producing quality output. Two rounds for the two teams were compared with each other. This exercise led to the identification of solutions to address areas of inefficiency (waste) in a process for a greener and more efficient process. The concepts learned through the session were finally summarized at a final discussion session to keep the students aligned with the overall workshop objectives.

Mechanical Engineering

One major application of CO_2 capture is to reduce the CO_2 emissions from coal-based power plants. The mechanical engineering class covered topics in thermodynamics relevant to the operation of coal-based power plants, as well as considerations for implementing CO_2 capture in these power plants. After a brief introduction to careers in mechanical engineering and topics covered in mechanical engineering curriculum, students were introduced to the steps required in the operation of a power plant through the Rankine Cycle. After some explanation and exploration of these steps, students were taught the definition of thermal efficiency and discussed how certain factors in the design and operation of a power plant may contribute to its efficiency. Students also discussed how thermal efficiency may relate to other forms of efficiency (generally, the ratio of the desired output to the required input).

In an activity related to these two topics, students worked in groups to build a simple heat engine (the basis for the operation of a power plant). The heat engine used a candle to heat water contained in copper coils, creating steam and rotational motion. Students were then asked to think of an equation which might represent the device's efficiency, and recorded measurements of the device's efficiency on a data sheet. During the first half of the activity, students built their heat engines by following a set of directions provided by the instructor. They then redesigned their heat engines with the goal of increasing the device's efficiency. At the end of the class, students were given questions to help them reflect on the activity and its connection to efficiency, the design process, and the operation of power plants. The instructor then led a brief discussion during which participant groups shared their results.

Analysis and Discussion

Several assessment methods were implemented to determine the effectiveness of the E-GIRL program with respect to each student's technical skills, self-efficacy, perception of engineering, and interest in engineering. Pre- and post-surveys asked program participants to rate their engineering skills and provide written responses regarding their interest in and perception of engineering. The pre-survey also collected demographic information and a set of factors which influence participants' interest in pursuing engineering. During their oral presentations at the end of the week, each group was rated by the six instructors on a scale from 1 (worst possible performance) to 4 (best possible performance) in categories related to delivery, content, and audience awareness. Participants also rated the instructors after attending each discipline-specific course.

Pre-Survey Participant Information

Figure 1 provides demographic information about program participants from the 2016 year. In total, 14 female students attended the program. The majority of the program's participants were Caucasian and were either 16 or 17 years old, coming from suburban communities. Both the demographics and number of participants differ from last year's program, where only 44% of 37 students identified as Caucasian (in contrast to 56% from this year's program). It is unclear why the number of students who participated in the 2016 program was smaller, as no significant changes to recruitment methods, cost, and time of year occurred between the two programs.

Information was also collected to determine possible reasons for program participants' interest in engineering. Figure 2 provides information about the motivating factors behind the students' interest in engineering (note that it was possible for participants to choose multiple options). The most prominent motivating factors were related to personal interests (for example, a desire to help people or an interest in math and problem solving) while other factors, such as money or recommendations from family, were less powerful motivators. Among people who affected the participants'

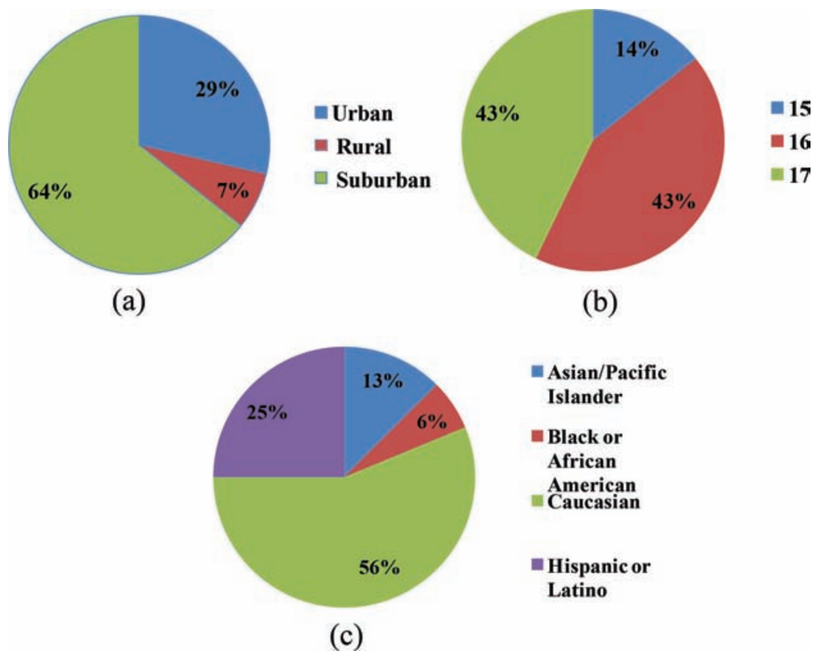

Figure 1. (a) Community type; (b) age; (c) race or ethnicity of program participants.

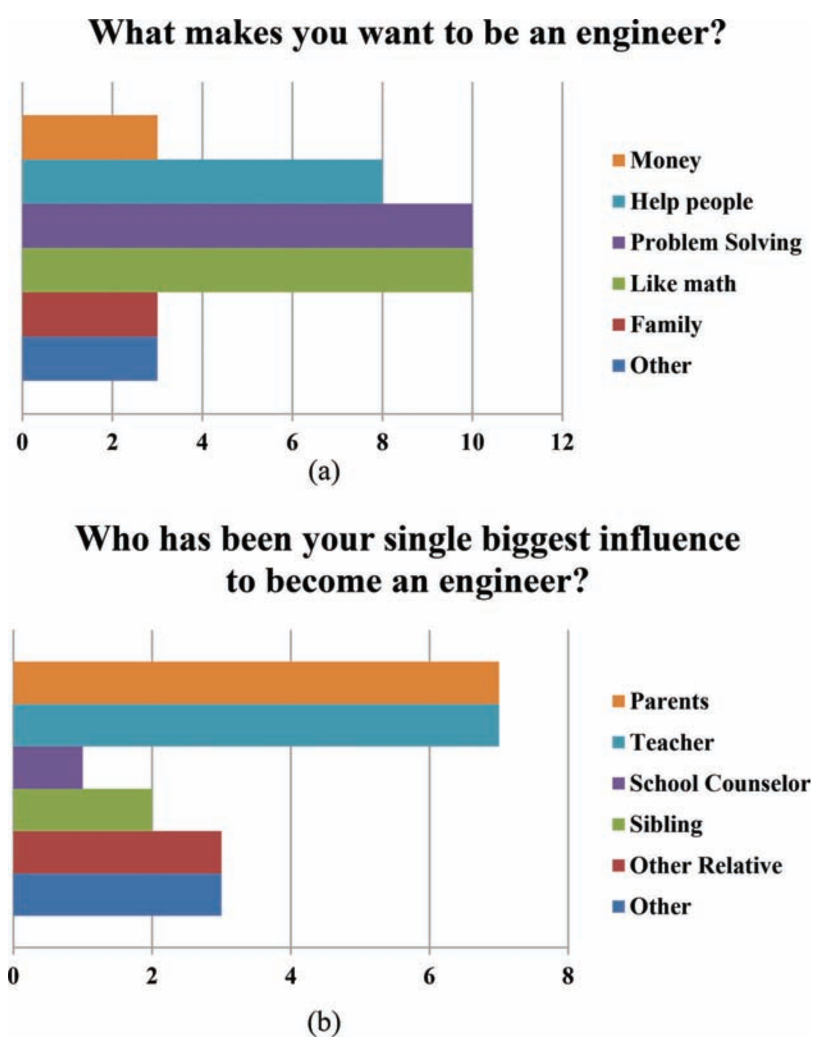

Figure 2. (a) Factors affecting interest in engineering; (b) people affecting interest in engineering.

desire to pursue engineering, parents and teachers were most likely to influence students' decision to become engineers. Most program participants considered becoming engineers for the first time during middle school or early high school (ages 12–16), and roughly half of the students had participated in a STEM outreach program prior to attending E-GIRL.

Students were also asked to rate their interest in and level of success with math and science, as well as their perception of its importance to engineering. Their responses are summarized in Table 2. On average, students have more interest and success in science than in math, but the average interest and success of students in both math and science are relatively high. While the level of importance of math in engineering matches well with students' interest and perceived success in math, the difference between students' interest and perceived success in science differs from their perceived level of the importance of science in engineering, even when the outlying values (shown in red) are neglected. It would be interesting to investigate this point further in the context of recruitment and retention of women in engineering. If more of an effort is made to emphasize the importance of science to engineering, female students may be more likely to pursue engineering, as it will better align with their interests and perceived success.

Students were also asked to provide written responses highlighting the aspects of math and science that they enjoy or do not enjoy. One aspect of math that many students appreciated is that there is always a right answer. While this point of view is not unexpected coming from high school students who are used to standardized tests, it is useful to note as a reason female students may be interested in engineering. Because it is rare for professional engineers or engineering students in upper level classes to encounter a problem with a distinct and identifiable right answer, the expectation of a right answer may lead to a lack of confidence or interest as they progress further in engineering. Program participants also noted they enjoy that both math and science have real-world applications, and they tend to enjoy math and science more when those real-world applications are emphasized.

Pre-to-Post Perceptions of Engineering

The pre-to-post survey requested written responses from program participants to the following two questions: (1) In your own words, define engineering; (2) explain why you want to become an engineer. The instructors in E-GIRL performed coding and identification of recurring themes from these written responses. The diagram in Figure 3 represents the most commonly occurring themes for each of these responses in the pre- and post-surveys. For the question, "In your own words, define engineering," there were few changes from the pre-to-post survey, with the exception that in the post-survey, several students mentioned specific disciplines of engineering in their responses. For this question, most students perceived engineering as a career which involves creativity, imagination, and problem solving, and which helps people. For the question, "Explain why you want to become an engineer," a noticeable difference emerges. After the program, the percentage of responses indicating that participants want to become engineers to help people nearly doubled. It is possible that this result is tied to the environmentally friendly theme for this year's program, which is likely to encourage program participants to consider solutions to problems that affect the environment or people.

Engineering Skills Assessment

Participants' self-development score of engineering skills was assessed using a Likert scale included in a before-and-after questionnaire. This questionnaire is similar to the one illustrated by Yew and colleagues (Yew, Monaco, Cloutier, & Morse, 2016) with minor modifications made. The changes ensure that comparisons can be made between previous results and current results, and maintain consistency in the results to enable long-term analysis in the future.

Table 2
Self-reported participant (n) ratings for math and science with respect to interest, success, and importance to engineering.

Math Interest Score	***n***	**Math Success Score**	***n***	**Math Importance Score**	***n***	**Science Interest Score**	***n***	**Science Success Score**	***n***	**Science Importance Score**	***n***
1	0	1	0	1	1	1	0	1	0	1	0
2	0	2	0	2	0	2	0	2	0	2	1
3	0	3	0	3	0	3	0	3	0	3	0
4	0	4	1	4	0	4	0	4	0	4	0
5	1	5	0	5	0	5	0	5	0	5	0
6	1	6	1	6	0	6	1	6	0	6	1
7	4	7	2	7	3	7	6	7	5	7	3
8	4	8	5	8	5	8	0	8	2	8	6
9	1	9	2	9	0	9	1	9	3	9	1
10	3	10	3	10	5	10	6	10	4	10	2
Average	7.9	Average	8.0	Average	8.0	Average	8.4	Average	8.4	Average	7.0
Std. Dev.	1.5	Std. Dev.	1.7	Std. Dev.	2.4	Std. Dev.	1.6	Std. Dev.	1.3	Std. Dev.	2.6

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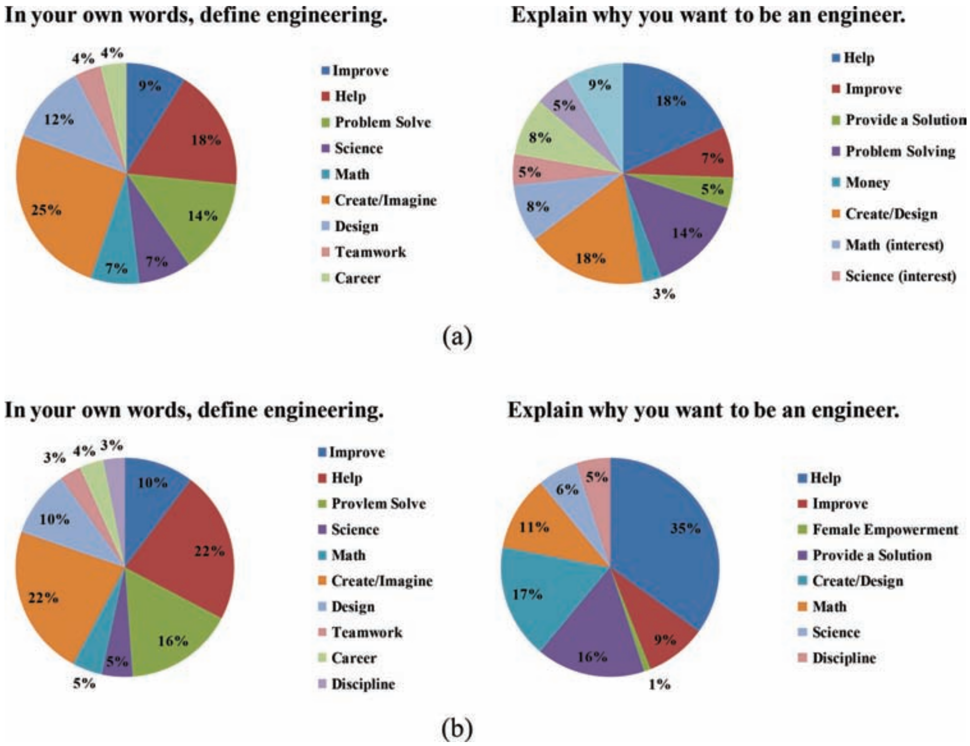

Figure 3. (a) Responses to pre-survey questions; (b) responses to post-survey questions.

Table 3
Statistical results of the engineering skills assessment.

Skills	Before Camp		After Camp		% Increase
	Mean	*SD*	Mean	*SD*	
Problem Solving Skills					
Ability to be creative	3.50	0.90	3.75	0.75	6.67
Think globally	2.91	1.16	3.83	0.94	23.91**
Think analytically	3.58	1.16	3.83	0.83	6.52
Attention to details	4.08	0.90	4.08	0.90	0.00
Technical understanding	3.17	1.27	3.75	0.62	15.56*
Math and science skills	4.00	0.74	4.08	0.67	2.04
Project Management Skills					
Organizational skills (tasks, deadlines)	3.92	1.31	4.25	0.62	7.84
Organizational skills (people)	3.33	1.23	4.00	0.85	16.67*
Time management	3.67	0.89	3.75	1.06	2.22
Utilization of resources	4.08	0.79	3.58	0.79	(13.95)
Teamwork					
Contribution to group tasks	4.17	1.19	4.33	0.89	3.85
Help with other tasks	4.00	1.04	4.25	0.75	5.88
Leadership skills	3.50	1.17	4.00	1.04	12.50*
Conflict resolution	3.50	0.90	3.92	0.67	10.64
Communication Skills					
Group communication	3.58	1.16	4.17	0.83	14.00*
Technical writing	3.58	1.16	3.25	0.75	(10.26)
Oral presentations	2.58	1.08	3.00	0.95	13.89
Listening skills	3.58	1.31	4.25	1.06	15.69**

**p*-value $\leq$ 0.1
***p*-value $\leq$ 0.05

Fourteen student responses were collected before and after the program to evaluate their competency in 18 skill sets that were identified to be important for engineers. A Wilcoxon signed rank test analysis was conducted to determine which skill sets recorded a statistically significant positive shift in perceived competency after the program. Table 3 shows the statistical analysis of the engineering skills assessment with the Wilcoxon signed rank test results included.

In general, results show an increase in self-efficacy scores in the engineering skills assessment, although two skills in particular—utilization of resources and technical writing—recorded a decrease in self-efficacy scores. The skill associated with attention to details remained the same before and after the program.

Participants recorded a self-efficacy drop in their capability to utilize resources, possibly due to their roleplaying multiple engineering disciplines. One team member may have roleplayed a civil engineer and a mechanical engineer, while the other may have roleplayed an industrial engineer and a chemical engineer. With most participants taking on two engineering roles, it is possible that they struggled to manage all of the provided information, and to relate it to the corresponding discipline.

Participants also recorded a drop in self-efficacy scores related to technical writing skills. As high school students, participants are not likely to have experienced extensive practice in technical writing, and are likely to have inaccurately assessed their initial capability in technical writing. As participants went through lessons on communication skills, they might have a better and more realistic understanding of their technical writing competency, which could have translated to a lower self-assessment of their technical writing skills.

Table 4
Summary statistics of student performance indicators.

Team	Average grade (out of 12) $n = 6$	Average grade (%) $n = 6$
#1	8.00	66.7
#2	9.58	79.9
#3	11.17	93.0
#4	11.08	92.4
Summary statistics		
Mean	9.96	83.0
Median	10.33	86.1
Variance	2.23	155.1
Standard deviation	1.49	12.5

Student Performance Indicators

Participants were assigned into four groups for the final oral presentations at the end of the program. Six instructors evaluated whether participants addressed the objectives of the project adequately, eloquently, and professionally. The presentations were evaluated based on three criteria: delivery, content, and audience awareness. Each criterion bears a possible maximum of four points (the best performance), and a minimum of one point (the poorest performance).

The grades for each group were collected, compiled, and used to calculate the summary statistics shown in Table 4. Average grades for each group range from a minimum of 66.7% to a maximum of 93%. The global average calculated from the averaged grades for each group is 83%. Overall, participants performed at least satisfactorily (i.e., a grade of 3 out of 4) in most of the criteria evaluated, and could address the objectives of the project adequately.

Although two of the teams produced consistently above-average results, participants mainly struggled with the open-endedness of the project which did not have a one-size-fits-all solution. Students were challenged to justify their choice of solutions economically and scientifically—a task and skill that is not often developed or emphasized among high school students. For many participants, the open-ended nature of the project affected their confidence in their proposed solutions, but instructors repeatedly reassured participants that this initial uncertainty is part of learning and training to be an engineer, and that an engineering student will eventually develop the necessary skills to be confident in his or her solutions. Participants' apprehension about the open-ended nature of engineering problems

Table 5
Assessment of instructors and courses by program participants.

Question	Average Rating
The instructor simulated student learning.	4.57
The instructor treated all students fairly and with respect.	4.92
The instructor allowed you to be active in the classroom learning environment.	4.73
The instructor encouraged students to speak up and be active in class.	4.50
The instructor welcomed and encouraged questions and comments.	4.54
The instructor was clear in giving directions and explaining what is expected on assignments.	4.18
The instructor planned class time and assignments that helped students to problem solve and think critically. Teacher provided activities that made subject matter meaningful.	4.36
The instructor emphasized the major points and concepts.	4.44
Overall, this instructor was effective.	4.49
The instructor demonstrated knowledge of the subject.	4.76
Overall, this course was a valuable learning experience.	4.63
The assignments and activities were relevant and useful.	4.62
Expectations were clearly stated either verbally or in the syllabus.	4.27
The workload was appropriate for the designated class time.	4.26

is a recurring theme, as participants in the previous E-GIRL program also expressed the same concern.

Course and Instructor Evaluation by Students

After attending each discipline-specific class, program participants were asked to rate both the instructor and the course on a Likert scale, where 1 corresponds to "Strongly Disagree" and 5 corresponds to "Strongly Agree." The results of these instructor evaluations are summarized in Table 5. Overall, the response to the discipline-specific courses was favorable, a trend which was also reflected in written comments by students. Two noticeable areas which may benefit from improvement include the clarity of instructions and time management on the part of the instructor. Although it can sometimes be difficult to predict how much time a particular group of students is likely to spend on a given activity, the issue of clarity may be addressed for future programs by including input on class content from others outside the instructor's field of expertise.

Conclusion

E-GIRL was a week-long, residential summer program provided for female high school students at TTU. The purpose of the program was to help participants gain knowledge about the role of engineers from a variety of disciplines in industry. Throughout the week, program participants attended courses for six engineering disciplines related to the unifying theme of CO_2 capture and storage. Participants also worked in teams to complete a group project related to this theme. In general, results showed an increase in self-efficacy and an enhanced understanding of the role of each engineering discipline covered in the program.

Based on feedback from the first year of the program, the most important changes for the 2016 year included the choice of a more altruistic theme and an extension of the time allotted for discipline-specific classes and activities. The choice of CO_2 capture as a theme aligned with the environmentally oriented interests of program participants from 2015 and was informed by previous literature concerning the interests of women who pursue STEM careers (Monaco et al., 2016; Yew et al., 2016). It was also clear from the feedback that participants valued the opportunity to gain experience with multiple disciplines of engineering. In both years, students expressed some discomfort with the open-ended project, which may have occurred for a variety of reasons. First, the program occurred over a relatively short period of time, during which students were often attending class or workshops. The small amount of time allotted to project work combined with the dense amount of information included in the program may have contributed to student unease. Second, because several students highlighted enjoyment of mathematics in connection with "always having a right answer," the open-ended nature of the project may have also been a contributing factor. However, because realistic engineering problems almost never have a distinct and identifiable right answer, it is important for students to become comfortable with open-ended problems. It is unclear what steps may be taken for future programs to address student feedback while still maintaining the open-ended project component. One possible approach is to address the issue of open-ended problems transparently at the beginning of the program, explaining that open-ended problems are realistic, and an inability to identify a clear correct answer is normal and should not necessarily lead to a loss in confidence.

In addition to changes in the program structure, assessments may benefit from changes as well. For example, the assessments currently focus heavily on the academic components of the camp while omitting other valuable components (such as the social aspect). Future assessments may collect feedback on social and other aspects of the program. Additionally, it may be useful to follow up with program participants several months after the program to collect feedback. Allowing some time for reflection may lead to more useful information about participants' overall experience.

The analysis discussed in this paper enhances the understanding of how to increase women's participation in engineering through the results of the students' self-assessments and their conceptions of engineering. The issues identified in this study can inform decisions about a classroom atmosphere that specifically addresses and accommodates for the needs and aspirations of women in engineering. The data collection and design of camp methodologies in E-GIRL can be implemented in the future design of engineering summer programs and can improve efforts to increase knowledge about the roles of specific engineering disciplines.

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