Evaluation of Interactive Multidisciplinary Curricula in a Residential Summer Program (Evaluation)

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Abstract

Previous studies have indicated that women account for about 18% of the engineering degrees awarded in the United States. Consistently low populations of women in engineering are often attributed to discrimination, the perception that engineering is a masculine domain, and a lack of understanding about the roles and responsibilities of an engineer. In order to increase participation of women in engineering, universities develop outreach programs designed to better educate students (and the public) about engineering. Programs in the form of information sessions, seminars or research activities are informative but often are not interactive or student-centered and may lack information about how different engineering disciplines interact in industry. To emphasize the multidisciplinary nature of engineering and to increase women's interest in pursuing engineering, a week-long residential summer program was created for female high school juniors and seniors implementing problem-based learning. Instructors from six engineering disciplines designed interactive and outcome-based topic lessons to introduce concepts and careers associated with their engineering fields. Lessons were structured to be student-centered using a flipped classroom model; students prepared for classes with short reading assignments, and class time was used for activities highlighting the engineering design process and physical concepts relevant to each discipline. To evaluate the efficacy of the lessons and the flipped classroom structure, a series of mixed assessment methods was implemented, which include: (i) instructor performance indicators – evaluated by students – measuring the quality of content, activities, delivery and relevance of the entire curriculum; and, (ii) students' self-assessment of key personal, interpersonal and intellectual traits before and after the program. Qualitative analysis of student responses to targeted prompts was also performed to observe shifts in students' perception of engineering during the program. Key results include high scores in instructor performance indicators, which suggest that adequate emphasis of relevant concepts by instructors during lessons, requisite student preparatory work before lessons, and interactive Q&A-style discussions contributed to a higher degree of perceived comprehension by students. Such high scores also support previous literature showing that students prefer an interactive, student-centered classroom structure. Qualitative results yield an evolved and matured perception of engineering among student participants and a more complete understanding of the individual engineering disciplines. Overall, evaluations led to the conclusion that the program structure was well received by students, and it sets the precedent for similar outreach programs in the future, enabling a continuous and long-term evaluation of the efficacy of an interactive curriculum.

Introduction

The importance of recruiting more students to science, technology, engineering, and math (STEM) majors and careers is well recognized. A 2010 report from the Business Higher Education Forum determined that increasing the number of people in STEM careers requires increasing both proficiency and interest in STEM[5], and student interest in STEM is increasingly being recognized as essential for strengthening the number of students who eventually choose STEM careers[22]. Currently, only 16% of American high school seniors are both proficient in math and interested in pursuing a STEM career. Among these students, only half eventually choose to work in a STEM-related career[24]. The problem of recruitment is even more pronounced for underrepresented groups in STEM fields such as black, Hispanic, and female students. A persistent gender gap exists for STEM majors and careers which involve rigorous math and science such as engineering[6]. Currently, the national average for women enrolled in undergraduate engineering programs is roughly 18%[5] and is 20% at Texas Tech University.

The difficulty of recruiting and retaining women in engineering stems from a variety of factors which can be summarized by several themes: low self-efficacy in STEM[4,12], differing expectations for male and female students[2], curricula which do not emphasize real-world problem solving[7], and a lack of institutional commitment to diversity[11]. Outreach efforts which address some or all of these factors have been effective for encouraging women to pursue engineering. The use of hands-on activities has proven particularly useful for enhancing female interest in engineering[14,18]. Additionally, providing female role models and special mentorships for women have been helpful for increasing self-efficacy[4,12].

Based on an evaluation of 34 successful outreach programs, Building Engineering and Science Talent highlighted the effectiveness of using student-centered teaching and learning methods to enhance student engagement[3], especially for female students[14,18]. One student-centered method which is growing in popularity is the flipped classroom, in which concepts are typically introduced prior to class using videos or reading materials, and class time is used for discussion, small group work, problem solving, or hands-on activities[15].Building Engineering and Science Talent also identified "defined outcomes and assessment" as one of five features of a program with positive outcomes[3]. Thus, the assessment of programs is of critical importance, both for documenting outcomes (summative assessments) and obtaining information geared toward program improvement (formative assessments)[23]. Assessments and evaluation tools for outreach programs are widely varied and are often created specifically for their particular programs. These evaluations are advantageous because they can assess only the outcomes considered relevant to the program; however, using assessment tools which are not standardized significantly lowers the likelihood that different programs may be compared. Some common methods are to evaluate students using after-program or before-and-after-program surveys in which students may rate their interest in STEM topics, knowledge of STEM careers, and attitudes toward STEM on a Likert scale. More generally, programs which aim to increase student interest in STEM may create evaluation tools targeted toward the domains of Engagement/Interest and Attitude/Behavior[9].

At Texas Tech University, a week-long, residential summer outreach program named E-GIRL (Engineering – Get Into Real Learning) was organized to promote and deepen interest in pursuing engineering degrees and careers among high school women. During E-GIRL, participants worked in teams to design a hydraulic fracturing site, a real-world problem which involves cooperation from many engineering disciplines. Each participant played a specific role on her team (i.e. served as a specific kind of engineer), and six college-style class periods, designed based on the flipped classroom format, were offered throughout the week to introduce concepts from six engineering disciplines as they relate specifically to the hydraulic fracturing problem. Previous implementations of the flipped classroom to an outreach setting could not be found in literature, indicating that the approach may be unique to this program, but a flipped classroom structure has been implemented in several college-level engineering classes[10,19,21]and has performed at least as well as the traditional lecture format. Most commonly, significant improvements in exam scores are not observed, but students report preferring the flexible and interactive nature of the flipped structure[13,22]. Applications of the flipped classroom environment in engineering courses have also been observed and recorded[25].

In this paper, the curriculum assessment of the six discipline-specific topic lessons in E-GIRL is presented. In addition to topic lessons, E-GIRL components include a real-world multidisciplinary group project, professional sessions and university information sessions. Detailed descriptions and a general E-GIRL program evaluation are presented in Monaco et al. (2016a)[16].

Methodology

The curriculum for E-GIRL aimed to promote interest in engineering among female students and provide a program allowing them to further explore engineering roles and experience university programs. The desired study outcomes for the discipline-specific lessons in E-GIRL are as follows: identify and distinguish among various engineering disciplines, excite female students to pursue engineering majors and higher education, introduce participants to opportunities the different engineering majors provide, and introduce key topics from six engineering disciplines to give students a more complete understanding of engineering.

Participant demographics

Thirty-seven participants were accepted into E-GIRL. Participant ages ranged between 15 and 17, corresponding to 9th through 11th grades in high school. The ethnic backgrounds of participants included Asian/Pacific islanders (5%), Black or African American (16%), Caucasian (46%), Hispanic or Latina (27%), Native American (5%), and other races (5%). Two participants included in the “other” category identified as Europeans and traveled from Rome, Italy to participate in E-GIRL.

Topic lessons

Six topic lessons were designed to introduce concepts and careers corresponding to civil, electrical, environmental, industrial, mechanical, and petroleum engineering. Each lesson lasted 90 minutes and was led by an instructor with expertise in their respective discipline. Lessons for each engineering discipline resembled a flipped classroom model. This lesson structure was implemented during E-GIRL to create an interactive environment and encourage discussion between students and instructors. A short reading covering key themes and background knowledge for each discipline was provided in a portfolio for participants at the beginning of the week. Participants were expected to review readings to gain a fundamental understanding of topics to be discussed during classes. Some assignments also included videos and other resources. Pre-class assignments allowed instructors to devote more time to interactive learning rather than lectures.

During class, students participated in hands-on activities which allowed them to develop problem solving skills and apply topics related to the hydraulic fracturing design project. The activities also provided examples of design requirements that various engineering disciplines might apply in the oil-and-gas industry. The interactive lesson for civil engineering covered foundation designs and facilities needed for the production sites. The electrical engineering session provided an activity for students to learn about sensors used in water level detection. Students were given the opportunity to construct their own sensors and test their designs. The environmental engineering session explored water/wastewater treatment through three separate activities: coagulation/flocculation, filtration and disinfection. The industrial engineering session introduced assembly line/supply chain concepts through a paper airplane simulation activity. The mechanical engineering lesson covered types of drilling procedures and included a pump design activity. Finally, the petroleum engineering lesson allowed students to use laboratory simulators highlighting fluid flow, the role of proppants in maintaining fracture openings, and the effect of permeability on production of hydrocarbons. The learning objectives for each discipline are summarized in Table 1.

Table 1: Lesson learning objective for six disciplines

Discipline	**Lesson Learning Objectives**
Civil	• Describe moment of inertia and how it relates to bending of structural members • Describe the distribution of forces over an area • Describe the consequences of constructing structures and infrastructure without proper foundations
Electrical	• Compare and contrast sensors using human senses • Design water level indicator and explain its purpose
Environmental	• Determine the ideal coagulant dosage for optimal settling of particles from solution • Demonstrate the physical removal of water contaminants • Compare and contrast the removal of dissolved and suspended particles • Design a filtration system capable of removing targeted contaminants and meeting design constraints • Understand adsorption properties and impact to water quality of different filter media • Calculate flow rate and loading rate of filter • Understand protection of public health via the removal of microbial contaminants in drinking water • Demonstrate how UV and chlorine are used to disinfect water
Industrial	• Describe the types of activities performed by industrial engineers • Identify and design solutions to address areas of inefficiency (waste) in a process – e.g. bottlenecks, inefficient or inconsistent procedures, failure to control material flow • Describe the role of industrial engineering and industrial engineers in oil-and-gas exploration.

Table 1 cont'd: Lesson learning objective for six disciplines

Mechanical	• Design a pump which raises fluid from a lower to a higher location • Design a pump which expels fluid at higher pressures than the example pump shown • Evaluate and redesign you pump • Describe the relationships among pressure, power, and flow rate
Petroleum	• Understand the definitions of porosity and permeability. • Explain how a proppant creates the permeable zone (hydraulically fractured area) and the impact of different sized proppants.

Analysis and Discussion

Engineering Skills Assessment

Participants' development of engineering skills was assessed using a Likert scale included in a before-and-after questionnaire. Appendix A provides the Likert assessment administered before and after participants completed the E-GIRL activities. Thirty-seven student responses were collected before and after the program where students evaluated their competency in 18 skills identified to be key for engineers. To determine whether there is a statistically significant positive shift in perceived competency before and after the program, the Wilcoxon signed rank test was performed. To evaluate the effect on students' technical competency in topic lessons and activities, the results related to problem solving skills are computed and tabulated as shown in Table 2. Similar results for the remaining 12 skills related to project management, teamwork and communication skills can be found in Monaco et al. (2016b)[17].

From Table 2, the mean score denotes the students' average self-rating of a skill based on a Likert scale from 1 to 5, where 1 indicates that the skill is undeveloped, and 5 indicates that the skill is fully developed. SD denotes the standard deviation.

Of the six skills associated with problem solving, five showed statistically significant increases in participant self-assessments. Skills that showed increase in self-assessment results can be attributed to the program which delivered new information, explained the application of important engineering concepts, and provided opportunities to put these engineering skills into practice while completing hands-on activities. This increase in self-efficacy is encouraging since women and men typically perform equally well on math skills assessments, but women consistently underrate their own abilities in STEM[1].

Table 2: Statistical Results from the Wilcoxon Signed Rank Test

Skills	**Before Camp**		**After Camp**		**% Increase**
	Mean	**SD**	**Mean**	**SD**	
Problem Solving Skills					
Ability to be creative	3.61	0.69	4.11	0.93	13.8***
Think globally	3.14	0.87	3.78	0.89	20.5***
Think analytically	3.36	0.96	3.84	1.09	14.2***
Attention to details	3.94	0.86	3.78	0.95	(4.1)

Technical understanding	3.28	1.00	3.73	1.02	13.8**
Math and science skills	3.75	1.00	4.00	1.08	6.7**

*$\boldsymbol{p-value \leq 0.1}$
**$\boldsymbol{p-value \leq 0.05}$
***$\boldsymbol{p-value \leq 0.01}$

Comments and feedback that were collected from the instructors after each topic lesson indicated that students made the effort to apply newly learned knowledge in examples and case studies that were being discussed in class. One of the instructor's comments remarked on solutions by students that did not work (in addition to those that did), which the authors contend is in line with the learning process and part of the frustration associated with the engineering design process. The authors further assert that getting students involved in some design provided a glimpse of the responsibilities of engineers. Instructors' comments further showed that students were able to connect engineering concepts with existing applications, going so far as to infer how the pumps they designed during their in-class discussion operate similarly to the human heart, or how a building constructed on poorly designed foundations (as illustrated in an experiment using weights on a bottle which was placed on a tub of dry sand) may collapse or lean like the Tower of Pisa. These instructor comments lend support to the statistical findings shown in Table 2, implying that upon the delivery of new engineering concepts, students showed better technical understanding and ability to think globally and analytically to find solutions.

Instructor Performance Indicators

At the end of each topic lesson, students were required to evaluate the instructors on their teaching, course material, and behavior in class (Appendix B). Students evaluated instructors on 14 items using a Likert scale between 1 and 5, with 1 being the poorest assessment of a particular item and 5 being the best, and their results were compiled in a spreadsheet. Summary statistics were calculated and tabulated as shown in Table 3 for each engineering discipline evaluated. The average results range from 69.2% to 95.4%. Of the six instructors, two obtained average ratings of above 90%, three received ratings between 80% and 90%, and one received a rating of below 70%.

Comments that accompanied some of these higher ratings indicate that students favored the way topic lessons were designed and delivered because students were provided with preparatory material to go through prior to entering the classroom. The gain of prior introductory information allowed students to formulate follow-up questions and to have fundamental understanding of the relevance of each engineering discipline in a given project. While the classroom model placed considerable responsibility on the students to complete their preparatory work, students appreciated the time allocated for topic lessons focusing on answering questions, delivering advanced material and completing hands-on activities. The authors observed that students who gave instructors higher ratings also indicated that the instructors emphasized on the relevance of their engineering discipline in the project and also in other industries – a key piece of information that students might use in deciding which engineering discipline to pursue in the future. Instructors who were able to connect hands-on activities to tangible applications were also viewed more favorably by students.

Table 3: Instructor Performance Indicators Summary Statistics (list of items assessed is available in Appendix B)

Discipline	Average (out of 70)	Average (%)
Electrical engineering	48.44	69.2
Mechanical engineering	65.13	93.0
Industrial engineering	57.29	81.8
Petroleum engineering	56.48	80.7
Civil engineering	66.76	95.4
Environmental engineering	57.52	82.1
Summary Statistics		
Mean	58.61	83.7
Median	57.40	82.0
Variance	43.98	89.8
Standard Deviation	6.63	9.5

However, students also noted the challenge of working on an open-ended project for which no "one size fits all" solution exists. The multidisciplinary nature of the project prompt added complexity and difficulty because it required students to dissect the project into multiple, smaller sub-projects that will fall under the purview of different engineering disciplines.

Frequency Analysis

A questionnaire was included asking students to differentiate among the various engineering disciplines and to summarize the focus of each discipline. Students' responses were collected before and after the program, then compiled in a spreadsheet to determine the number of engineering disciplines students mentioned. This was done to observe whether students gained knowledge about engineering disciplines with which they were unfamiliar before the program. To present the information in a meaningful manner, Table 4 shows the fraction (in percentages) of students who made mention of specific engineering disciplines before and after the program.

The acronyms for each discipline listed in Table 4 are defined as follows:

- CE – Civil engineering
- EE – Electrical engineering
- EnvE – Environmental engineering
- IE – Industrial engineering
- ME – Mechanical engineering
- PE – Petroleum engineering

Table 4: Percentages of students who made mention of specific engineering disciplines

Percentage population of students (%)						
Discipline	CE	EE	EnvE	IE	ME	PE
Before	46.0	54.0	37.8	8.1	48.7	46.0
After	73.0	75.7	81.1	70.3	78.4	64.9

Results show that engineering disciplines which were covered during the program recorded higher numbers of mentions after the program. Prior to the program, only three out of thirty-seven students made mention about industrial engineering, but that number increased to twenty-six at the end of the program. The results reflect the increase in student exposure to other engineering disciplines beyond any existing prior knowledge.

To better assess students' understanding of each engineering discipline that was covered and their ability to distinguish between them, a rating based on a Likert scale was applied to each student response on the same questionnaire based on the following scale definition:

- 0 – Student did not list any engineering discipline
- 1 – Student only listed engineering disciplines
- 2 – Student listed and summarized the scope of two engineering disciplines
- 3 – Student listed and summarized the scope of three engineering disciplines
- 4 – Student listed and summarized the scope of four or more engineering disciplines

By assigning a rating to each of the 37 responses taken before and after the program, a bar graph is plotted to illustrate the shift in students' ability to list and summarize the scope of engineering disciplines before and after the program. The graph is shown in Figure 1.

Results show that at the end of the program, more students were able to differentiate the scopes for a greater number of engineering disciplines, which indicate that students are more cognizant of the multidisciplinary nature of engineering, not just in their ability to list engineering disciplines, but also in their ability to express what each discipline does in their own words.

The reader is also directed to Monaco et al. (2016b)[17] for further information on how students performed academically in completing the requirements of the project.

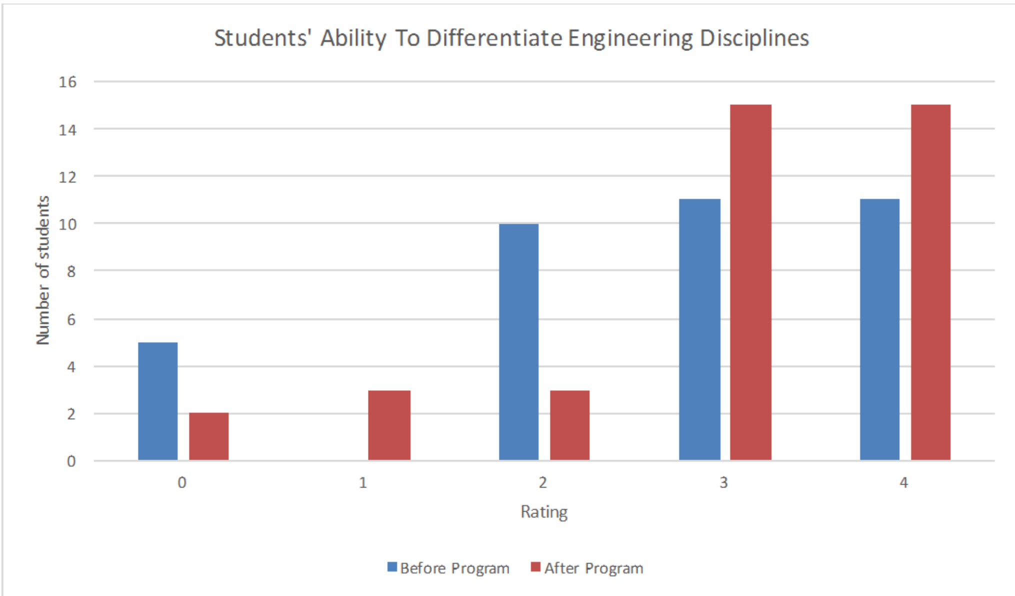

Figure 1: Before and after results showing students' ability to list and summarize the scope of engineering disciplines

Conclusion

At the end of the program, students showed improved understanding and capability in identifying and differentiating the scopes of the various engineering disciplines. Through engineering topic lessons designed to cover the multidisciplinary aspects of a project, students experienced first-hand the complexity and difficulty involved in addressing just the fundamental conceptual components of a project. Key engineering concepts introduced to students, coupled with hands-on activities, improved students' technical understanding and enabled them to connect fundamental physical and mathematical skills and apply them to an actual engineering project. Even though the flipped classroom model placed considerable responsibility on students to complete their preparatory work prior to entering the classroom, students received this model well because lesson time could be used to answer questions about the preparatory material, to cover advanced material and to complete hands-on activities, all of which are designed to provide students with a more holistic approach to education and to promote technical competency beyond the limits usually achieved in a traditional classroom environment.

Future Work and Recommendations

As E-GIRL received favorable feedback from students, the program is scheduled to be held for the second time in 2016 with higher anticipated participation rates. This allows for a larger sample size in data collection and provides the opportunity to address shortcomings in the assessments. By improving and revising current assessment methods, the authors hope to address issues that were not covered in this paper, e.g. the number of students who expressed a desire to pursue engineering before the program versus after the program.

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Appendix A: Engineering Skills Assessment (administered before and after program)

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ENGINEERING: GET INTO REAL LEARNING

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Engineering Skills Assessment

Name: ____________________ **Date:**____________________

Rank each of the skills listed below in order of how important you believe they are for an engineer to have (1 being most important, and 22 being least important). Then, on a scale of 1-5, how well developed you are in that skill (1 being not developed at all, 5 being fully developed).

Skills	**Importance for Engineering (Rank 1-22)**	**Self-Development Score (Rate yourself on a scale of 1-5)**
1) Problem solving skills		
a) Ability to be creative		
b) Think globally		
c) Think analytically		
d) Attention to details		
e) Technical understanding (knowledge of subject)		
f) Math and science skills		
2) Project management		
a) Organizational skills (tasks, deadlines, etc.)		
b) Organizational skills (people)		
c) Time management (meeting deadlines and submittals)		
d) Utilization of resources		
3) Teamwork		
a) Contribution to group tasks		
b) Help others with tasks		
c) Leadership skills, ability to lead tasks		
d) Conflict resolution		
4) Communication skills		
a) Group communication of needs, accomplishments and next steps		
b) Technical writing (including written reports)		
c) Oral presentations		
d) Listening skills		

Appendix B: Participant rating on instructor performance assessment

Instructor Evaluation by Students

Name/Class: ____________________ **Date:**___________________

The number rating stands for the following; **1** = rarely **2** = once in a while **3** = sometimes **4** = most of the time **5** = almost always. Circle the answer that fits your experience of this instructor for each item.

	Rating					Comment
The instructor stimulated student learning	1	2	3	4	5	
The instructor treated all students fairly and with respect	1	2	3	4	5	
The instructor allows you to be active in the classroom learning environment	1	2	3	4	5	
The instructor encourages students to speak up and be active in the class	1	2	3	4	5	
The instructor welcomed and encouraged questions and comments	1	2	3	4	5	
The instructor is clear in giving directions and on explaining what is expected on assignments	1	2	3	4	5	
The instructor plans class time and assignments that help students to problem solve and think critically. Teacher provides activities that make subject matter meaningful	1	2	3	4	5	
The instructor emphasized the major points and concepts	1	2	3	4	5	
Overall this instructor was effective	1	2	3	4	5	
The instructor demonstrated knowledge of the subject	1	2	3	4	5	
Overall this course was a valuable learning experience	1	2	3	4	5	
The assignments and activities were relevant and useful	1	2	3	4	5	
Expectations were clearly stated either verbally or in the syllabus	1	2	3	4	5	
The workload was appropriate for the designated class time	1	2	3	4	5	