Assessment of K-12 Outreach Group Project Highlighting Multidisciplinary Approaches in the Oil and Energy Industry

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Assessment of K-12 outreach group project highlighting multidisciplinary approaches in the oil and energy industry

Abstract

A need exists to inspire female high school students to study engineering, and one approach is to expose students to the different engineering disciplines and highlight current technological problems that require multidisciplinary approaches. The objective of a week-long residential summer program was to introduce high school females to six engineering disciplines and multidisciplinary approaches through interactive topic lessons, a real-world group project and professional development sessions to excite female students about current engineering applications and careers. The group project tasked students with the problem of designing and implementing a hydraulic fracturing site given a variety of site condition design constraints. The interactive structure of the open-ended design project uniquely provided high school students with the opportunity to gain personal, interpersonal and technical engineering skills while highlighting the significance of multidisciplinary approaches to current technological advancements within the oil and energy industry. Assessment instruments of student performance during the group project included: (a) an oral presentation rubric utilized by program instructors to evaluate team presentations on delivery, content, organization, and audience awareness; (b) pre- and post-program questionnaires to evaluate the impact of the team project on students' grasp of the importance of multidisciplinary design approaches; and (c) a pre- and post-program Likert scale assessing student perception in self-development of engineering skills following the completion of the group project and summer program. The evaluation of the team presentations indicated that following the completion of the summer program's open-ended project, students were able to work in multidisciplinary teams while explaining the roles the different disciplines culminating to an engineering design.

Introduction

The application of real-world experiences and problem solving to engineering curricula is being recognized with increased importance. Evidence has shown that students tend to show increased interest and confidence for tasks which have realistic context.[4] This trend is especially true for female students,[4,8] a population that is largely underrepresented in engineering. In particular, female students are more likely to prefer problems with a social context, whereas males are more likely not to notice the context.[11] Programs which incorporate real-world problem solving and experiences are thought to produce college graduates who are better prepared and more globally competitive.[12]

By nature, real-world problem solving is multidisciplinary and team-oriented. In general, teamwork has been shown to improve skills necessary for engineering students' future careers, including leadership, communication, time management, and group problem solving.[9] The importance of multidisciplinary collaboration is reflected in ABET requirements stating that engineering graduates should be able to function in multidisciplinary teams.[2] However, exposure to multidisciplinary work in the classroom is often limited. Further, many graduating high school students do not know enough about the various engineering disciplines to make informed choices about college majors.

This paper describes a week-long, residential summer outreach program called Engineering: Get Into Real Learning (E-GIRL) which was implemented at Texas Tech University (TTU) for the first time in the summer of 2015. The goal of the program was to enhance interest in pursuing engineering for the group of 37 high school women who attended. Participants were divided into multidisciplinary teams of engineers and were asked to solve a real-world problem (in this case, designing a hydraulic fracturing site). College-style lectures and activities were provided introducing students to content from six engineering disciplines, both general and related to hydraulic fracturing. At the end of the week, each team presented their work, justifying design choices based on the content provided from lectures and activities on each discipline. This paper focuses on the major hydraulic fracturing project assessment.

The National Academies Press provides detailed information on 29 programs which successfully incorporate real-world experiences into engineering education.[12] In literature, the most popular way of integrating real-world problem solving, especially in multidisciplinary teams, seems to be through capstone design courses. As of 2005, roughly 35% of undergraduate capstone design projects were conducted in multidisciplinary teams of students (an increase from 21% in 1994).[6] Evidence has shown, both qualitatively and quantitatively, that students benefit greatly from working in multidisciplinary settings. Survey results show that engineering professionals associate interdisciplinary thinking with creativity in their peers and rate multidisciplinary work as very important in preparation for industry.[7] Similarly, students who participated in a multidisciplinary capstone course identified functioning in a multidisciplinary team as key to their future careers.[1] Most compellingly, quantitative results have revealed that all students who participated in the multidisciplinary course, compared to the monodisciplinary course, produced a better engineering solution as judged by external industry professionals.[3,5] Further, students in the multidisciplinary course performed better in utility, analysis, proof of concept, and communication skills.

Multidisciplinary outreach efforts are less common but do exist in literature. One frequently used tool for multidisciplinary research is robotics, which is a topic that ordinarily requires background in electrical engineering, mechanical engineering, industrial engineering, and computer science. In robotics, working in multidisciplinary teams allows students to see the interaction among various systems without needing an overwhelming amount of background information[14]. An application of a real-world, multidisciplinary outreach project on hydraulic fracturing is unique to the program presented in this paper.

This paper is organized as follows. First, the design of the camp is described, paying special attention to the multidisciplinary group project. Results of the engineering skills assessment and oral presentation evaluations by instructors are then presented and discussed. The authors primarily aimed to determine how the camp, and specifically the group project, affected participants' project management, teamwork, and communication skills. Finally, concluding remarks are provided.

Methodology

The E-GIRL curriculum included many activities aimed to excite female high school students about engineering and pursuing university studies. E-GIRL was structured to introduce participants to engineering lessons and the typical schedule of an engineering student. Detailed information of the complete E-GIRL curriculum is presented in Monaco et al. (2016).[10] This paper details the structure and assessments of the multidisciplinary group project as part of E-GIRLs first year curriculum. Among the goals of the multidisciplinary project were to provide an engineering design project introducing students to real-world problems, highlight the importance of multidisciplinary teamwork through a group project, develop project management skills, teamwork and communication skills, and expose participants to current engineering applications relevant to their community.

Participant demographics

Table 1 summarizes the demographic backgrounds of 37 program participants. Ethnic backgrounds of Black or African American, Caucasian, and Hispanic or Latina represented 16%, 46%, and 27% of the student population, respectively. Two participants from Rome, Italy identified as European and are included as Other in Table 1. The majority of participants were seventeen years old at the time of enrollment and represented 9th through 11th grades in high school. Participant backgrounds represented a variety of types of communities and varying regional, state and international locations.

Table 1: Participant demographic backgrounds

Ethnicity	n	%	Age	n	Community	n
Asian/Pacific Islander	2	5	14	0	Rural	5
Black or African American	6	16	15	5	Suburban	23
Caucasian	17	46	16	10	Urban	8
Hispanic or Latina	10	27	17	22		
Native American	2	5				
Other	2	5				

Multidisciplinary project curriculum

A comprehensive group project served as a component of the E-GIRL summer program curriculum to develop participant project management, teamwork and communication skills. Students were grouped into teams of four or five and were assigned various engineering roles. The project statement tasked groups to submit conceptual designs to develop, justify, and document design, as well as develop a cost analysis for the construction of a hydraulic fracturing well. The project statement was presented to participants at the beginning of the week providing them with the background information prior to attendance for various topic lessons. Background information provided teams with the knowledge of potential roles that civil, electrical, environmental, industrial, mechanical, and petroleum engineers have in the development of fracturing sites. Team members were to select which engineering role they would serve during the project. During the week, study and team meetings were included to provide time for collaboration amongst the group members. The project provided students with an activity present in undergraduate design courses and challenged participants to develop organizational skills, time management skills, contribution to group tasks, and technical presentation. Each group was provided a different site location with unique constraints to diversify design selections based on individual site parameters.

Teams presented conceptual design alternatives through a 15-minute oral presentation meeting tasked project objectives. Each team member was required to speak during the oral presentation describing her role designing the final product. Following the oral presentation, a 5-minute question-and-answer session allowed the audience to gain clarity or further inquire about a team's presented information. The audience included lesson instructors, counselors, fellow E-GIRL participants and parents. Teams had the opportunity to present information to an audience with a broad level of understanding of subject matter.

The question-and-answer session tested the level of comprehension and provided individuals another opportunity to express their knowledge and justify why specific design recommendations were selected. Through the project assigned during the summer program, student had the chance to strengthen project management, teamwork and communication skills and to apply problem solving skills. Uniquely, participants received feedback from a diverse audience and were tasked with the challenge of being able to effectively communicate to an audience of varying education and expertise levels, lending support to the importance of good technical communication.

Assessment instruments

Self-development assessment by students using a Likert scale was administered before and after the completion of E-GIRL. Assessment included participants' self-scoring of engineering skills in four main categories: problem solving, project management, teamwork and communication. Table 2 provides the assessment administered to participants before and after the completion of program activities. Students were asked to rank each of the skills listed in order of how important they believed the skills were for engineers to exhibit (1 being "most important", and 22 being "least important"). Then, students were asked to rate, on a scale of 1-5, how well developed they are in that skill (1 being "not developed at all", 5 being "fully developed").

Team oral presentations were assessed according to the rubric shown in Table 3. The grading rubric was utilized by instructors present during team presentations and the question-and-answer session. Instructors provided a score based on delivery, content/organization and audience awareness. Table 3 provides information on each category and the scoring scale. In addition to an assigned score, instructors provided written comments highlighting strengths and areas for improvement following the oral presentations by each team.

Table 2: Engineering skills assessment

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		

Table 3: Oral presentation rubric

	4	3	2	1
Delivery	Holds attention of entire audience with the use of direct eye contact, seldom looking at notes. Speaks with fluctuation in volume and inflection to maintain audience interest and emphasize key points.	Consistent use of direct eye contact with audience, but still returns to notes. Speaks with satisfactory variation of volume and inflection.	Displays minimal eye contact with audience, while reading mostly from the notes. Speaks in uneven volume with little or no inflection.	Holds no eye contact with audience, as entire report is read from notes. Speaks in low volume and/ or monotonous tone, which causes audience to disengage.
Content/ Organization	Demonstrates full knowledge by answering all class questions with explanations and elaboration. Provides clear purpose and subject; pertinent examples, facts, and/or statistics; supports conclusions/ideas with evidence.	Is at ease with expected answers to all questions, without elaboration. Has somewhat clear purpose and subject; some examples, facts, and/or statistics that support the subject; includes some data or evidence that supports conclusions.	Is uncomfortable with information and is able to answer only rudimentary questions. Attempts to define purpose and subject; provides weak examples, facts, and/ or statistics, which do not adequately support the subject; includes very thin data or evidence.	Does not have grasp of information and cannot answer questions about subject. Does not clearly define subject and purpose; provides weak or no support of subject; gives insufficient support for ideas or conclusions.
Audience Awareness	Demonstrates strong enthusiasm about topic during entire presentation. Significantly increases audience understanding and knowledge of topic; convinces an audience to recognize the validity and importance of the subject.	Shows some enthusiastic feelings about topic. Raises audience understanding and awareness of most points.	Shows little or mixed feelings about the topic being presented. Raises audience understanding and knowledge of some points.	Shows no interest in topic presented. Fails to increase audience understanding of knowledge of topic.

Results and Discussion

Engineering Skills Assessment

Thirty-seven student responses were collected before and after the program where students evaluated their competency (self-development) in 18 skills identified to be key for engineers. Authors noted data was inconclusive for the students ranking of skills important to engineering due to confusion in ranking instructions provided when assessment tool was administered. 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. In this paper, the skills related to project management, teamwork and communication skills were assessed. The results shown in Table 4 present summer 2015 E-GIRL assessment data. Six of the engineering skills related to problem solving are not discussed here but are presented in the Yew et al. (2016) as these skills are not within the scope of this paper.[15] From Table 4, the mean score refers to the students' average self-rating of a skill based on a Likert scale between 1 and 5, where 1 indicates that the skill is undeveloped, and 5 indicates that the skill is fully developed. SD stands for standard deviation.

Table 4: Statistical Results from the Wilcoxon Signed Rank Test

Skills	Before Camp		After Camp		% Increase
	Mean	SD	Mean	SD	
Project Management Skills					
Organizational skills (deadlines)	3.64	0.96	3.92	1.04	7.7**
Organizational skills (people)	3.47	1.08	3.892	0.84	12.1**
Time management	3.61	0.99	3.97	0.92	10.0**
Utilization of resources	3.81	0.82	3.92	0.93	3.0
Teamwork					
Contribution to group tasks	4.25	0.84	4.03	0.90	(5.3)
Help others with tasks	3.86	0.80	4.00	0.94	3.6
Leadership skills	3.94	0.89	3.97	0.99	0.7
Conflict resolution	3.78	0.96	3.89	1.07	3.0
Communication Skills					
Group communication	3.58	0.84	3.81	0.88	6.4*
Technical writing	3.15	1.06	3.49	0.96	10.6**
Oral presentations	3.26	1.15	3.62	1.01	11.0**
Listening skills	4.11	0.85	4.30	0.94	4.5

$*p - value \leq 0.1$

$**p - value \leq 0.05$

Out of the twelve skills shown in Table 4, only six showed statistically significant increases in these self-assessments at the end of the program. None of the skills associated with teamwork recorded a statistically significant increase in the self-assessments, and the skill highlighting contribution to group tasks even recorded a drop in the self-assessments. While students may have had experience working in teams, cooperating in a multidisciplinary environment where each team member is responsible for roleplaying a specific engineering discipline requires them to trust their team members to perform adequately. Should their team members fall short, other members may have difficulty allocating time to provide assistance without neglecting their own responsibilities. In the end, if students perceived that the overall performance of the group could have been better, then any additional input from them – no matter how little – could have assisted their members to address any shortcomings.

Students who rated their teamwork skills lower after the camp might have come to realize that working together in multidisciplinary teams is more challenging than what they first anticipated. Students must possess patience and good soft skills which require practice, determination and perseverance. These are traits that cannot be mastered through lessons alone and require time and experience to develop the needed mastery.

The authors have accepted results with p-values of up to 0.10 to be statistically significant. While $p \leq 0.05$ is a commonly used statistical significance borderline in rejecting or failing to reject a null hypothesis (i.e. there is no increase in self-assessment ratings), working with small data sets means that – all else being equal – the standard errors calculated will be greater than those for large data sets. This causes p-values to exceed 0.05, which indicate a weaker evidence against the null hypothesis just by virtue of having small data sets. By accepting a significance level of 0.10, a 10% risk of rejecting the null hypothesis in error is incurred, which the authors believe is justifiable given the size of the data set.

Comments and feedback collected from instructors after each topic lesson indicated that students were initially hesitant to speak up and required some encouraging from student counselors to respond. With many of the discussed engineering concepts appearing new and foreign to students, such initial discomfort and hesitation to express their ideas and opinions was anticipated.

However, results in Table 4 – specifically on communication skills – indicate that as the program progressed, students perceived that they ended the program as better communicators in general. A classroom session by the local Toastmasters club covering important communication skills and tips on preparing for formal presentations provided a structure that students could adopt to communicate professionally and confidently. Opportunities for students to clarify concepts with instructors and the preparation time that students were given in anticipation of their oral presentations also enabled them to boost confidence and communicate their solutions to the audience better.

Student Performance Indicators

Students were divided into eight groups with six instructors evaluating the final oral presentations at the end of the program. Instructors evaluated the group presentations on three criteria: delivery, content and audience awareness. Each criterion was evaluated on a scale between 1 and 4, with 1 being the lowest rating (poorest performance) and 4 being the highest (best performance).

The grades for each group were compiled, and summary statistics were calculated. The results are shown in Table 5, which illustrate a spectrum of grades ranging from 71.5% to 88.2%. Of the eight groups, five scored a grade of 80% or better. In these groups, students addressed each engineering discipline requirements in greater detail and proposed solutions that are backed up by sound reasoning, be it from a technical, cost or safety standpoint. They also proposed solutions based on material beyond what was presented in the classroom, demonstrating considerable effort in research and considering potential technical issues beyond what was given in the project prompt.

The mean of the grades, from Table 5, is 80.7% (or 9.69 out of 12). Based on the rubric used by the instructors to evaluate students' presentations, students tended to perform at least satisfactorily (i.e. at least a grade of 3 out of 4) in all of the criteria evaluated and met expectations laid out in the project.

Such results were not unexpected, as the challenge associated with multidisciplinary projects is such that a team must dissect a project into multiple, smaller sub-projects – each falling under the purview of a particular engineering discipline. Coupled with the open-ended nature of the project for which no "one size fits all" solution exists, students (through their comments and feedback) found that actual engineering works with multidisciplinary aspects are more complex and more challenging than they anticipated. Analyzing a project from multiple engineering viewpoints required students to allocate and delegate manpower and other resources among their team members, stretching their team confidence thin. Each team member was responsible for her own solutions and was expected to work independently, but at the end must be able to produce results and convince other team members of her adopted solutions. The design of this program placed students in uncomfortable positions where the capabilities and trustworthiness of each team member were tacitly questioned. However, students appreciated that the open-endedness of engineering projects indicates a wide range of possible solutions, and the selection of any solution must be backed up by sound engineering reasoning and cost justification.

Table 5: Summary Statistics of Student Performance Indicators

Team	Average grade (out of 12) n = 6	Average grade (%) n = 6
#1	10.25	85.4
#2	8.75	72.9
#3	10.58	88.2
#4	10.08	84.0
#5	9.67	80.6
#6	9.00	75.0
#7	8.58	71.5
#8	10.58	88.2
Summary Statistics		
Mean	9.69	80.7
Median	9.88	82.3
Variance	0.66	46.1
Standard Deviation	0.81	6.8

Conclusion

At the end of the program, students experienced the multidisciplinary nature of engineering projects which required them to develop project management skills, teamwork and communication skills. Among the three skill sets, students found skills related to teamwork challenging to develop as these skills require practice, patience and determination; they are also skills that cannot be learned simply by attending lessons. Developing skills related to teamwork also requires students to develop interpersonal communication skills, potentially putting them out of their comfort zones. Students showed improvement in communication skills through participation during topic lessons and applying presentation techniques imparted to them in their oral presentations. Students also perceived improvements in project management skills given that the multidisciplinary nature of the project required them to divide the workload and delegate responsibilities fairly to address individual engineering components of the project. Assessment of the oral presentations by instructor's show that students performed satisfactorily and addressed the multidisciplinary nature of the project successfully, which the authors contend is remarkable given the magnitude of the project and the technical expertise that high school students possess. E-GIRL curriculum will be offered summer 2016, replicating the program structure outlined in this paper. The structure of the multi-disciplinary project will be similar to the hydraulic fracturing project; however, the topic of the engineering problem will be altered to introduce other engineering issues in the oil and gas industry.

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