Engaging Current and Future Engineering Students Using PBS Design Squad

Sirena Hargrove-Leak[1]

Abstract – There is concern that the United States is facing the dual challenge of a shortage of practicing engineers and lack of competitiveness in engineering in the global market. Therefore, as we define the educational needs of the engineer of 2020, service-learning should be a part of the discussion because of its potential to impact college students studying engineering and pre-college students exploring possible career paths. This paper describes one approach implemented in a partnership with first-year engineering students and elementary students using PBS Design Squad design challenges. Increased engagement in the course, deepened curricular knowledge, more interest in civic engagement, and improved communication skills were among the benefits cited by first-year engineering students. The elementary students demonstrated increased awareness of the engineering profession and an ability to engage in engineering design. There is also potential for additional longer term benefits such as improved achievement in science and mathematics.

Keywords: service-learning, first-year experience, K-12 outreach

INTRODUCTION

Engineers serve humankind by applying their knowledge of mathematics and science to solve problems. Many students are turned away by the mention of math and science in this definition or negative perceptions of the typical engineer. Among those who endure, some are driven by their desire to serve and others are excited about solving practical problems. Then, when they become engineering students they quickly realize that most of their time is spent acquiring the necessary disciplinary knowledge to become competent practicing engineers. The acquisition of knowledge often involves unimaginative instruction and little emphasis on practical applications; therefore, that aforementioned endurance is short lived for many students.

A variety of initiatives have been established to address these recruitment and retention issues. Numerous efforts targeted at K-12 students have emerged, including curriculum/material development for physical classrooms, online resources, summer camps, and pre-service teacher training. Retention efforts include a range of experiential education approaches such as laboratory activities, design projects, and service-learning.

The Engineering Education for a Changing World report released by the American Society for Engineering Education (ASEE) [2] states, "Today, engineering colleges must not only provide their graduates with intellectual development and superb technical capabilities, but following industry's lead, those colleges must educate their students to work as part of teams, communicate well, and understand the economic, social, environmental and international context of their professional activities." Therefore, although the aforementioned retention and recruitment initiatives typically function independent of one another, I claim that they can function well together to broaden the education of engineering students. A combined approach can positively impact both student groups while addressing retention and recruitment issues. This paper discusses one method used in a freshman engineering course at Elon University, where online resources were used to teach engineering concepts to primary students in a service-learning partnership with a local elementary school.

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LITERATURE REVIEW

While there are many definitions of service-learning, Jacoby and Associates have comprehensively defined it as "the integration of academic subject matter with service to the community in credit-bearing courses, with key elements including reciprocity, reflection, coaching, and community voice in projects" [6]. There is evidence that service-learning compliments the education of college students by making them more engaged, deepening their disciplinary knowledge, and encouraging civic engagement [Strage, 15].

The real world context of service-learning is a refreshing departure from the traditional lecture or textbook problem set for most students. The resulting improved student engagement is essential for the retention efforts, for it is well-known that students whose attention is piqued and sustained tend to remain in the major. It can also speak to the additional skills ASEE [2] says graduates need depending how the service-learning experience is executed. Other authors have reported evidence of improved communication and team work skills among engineering students involved in service-learning (e.g., [Cejka et al., 3], [Crumbaugh et al., 4], [Lord, 14]). Duffy et al. [9] additionally note improved "motivation to continue in engineering" in a number of disciplinary courses.

ASEE [2] encouraged partnerships with K-12 schools to adapt engineering education to meet the needs of a rapidly changing world. It is believed that this will yield better math, science, and technology instruction for K-12 students and inspire some of those K-12 students to consider an engineering profession. This is key to national and international economic, societal, and environmental health because these three areas are driven by technology, which has engineering at its very foundation. Economic, societal, and environmental health also depend on talented young people to replace the significant number of engineers and technically skilled professionals at or near retirement [Denton, 6, Jackson, 11].

National Academy of Engineering (NAE) and National Research Council (NRC) recently completed a broad review of K-12 engineering education over the past 15 years [Katehi et al., 12]. They were able to identify the following potential benefits for elementary students:

- improved learning and achievement in science and mathematics;
- increased awareness of engineering and the work of engineers;
- understanding of and the ability to engage in engineering design;
- interest in pursuing engineering as a career; and
- increased technological literacy.

The word potential stands out here because this is a relatively young field for which a strong body of research evidence is still developing.

As you might expect, similar work to combine recruitment and retention efforts by bringing engineering majors and primary or secondary students together has been reported by other authors. Some representative examples will be discussed in the remaining paragraphs in this section. The similarities and differences in approach are of particular interest.

Cruz-Rivera [5] also recognizes that "if we combine community service learning practices with our K-12 training and enhancement programs, we will increase enrollment and retention in engineering programs and provide our graduates with the skills required by the new workplace." He used four approaches at the University of Puerto Rico-Mayagüez: a two-week residential summer program for high school students, a one-day workshop for high school students, a year-round teacher training and enhancement center for teachers, and establishment of Future Scientists and Engineers of America (FSEA) clubs at schools. Each initiative makes use of engineering students as full-time staff members, facilitators for special presentations, mentors, and/or material development. The primary difference in his approach is that the engineering students volunteer to participate, rather than being required to do so as part of a class.

Cejka et al. [3] at Tufts University have also found that engineering students' benefit from further development of their communication skills, teamwork skills, and interest in citizenship when they are involved in engineering educational outreach. They operate a center whose goal is to increase "technological literacy within K-12 education systems in the Boston area." One program that operates out of the center "pairs engineering undergraduate and graduate engineering students (fellows) with K-12 educators." The engineering students' primary role is to work in partnership with the K-12 teacher to develop materials and activities for hands-on engineering instruction. As in the previous example, the engineering students choose to participate, rather than being required to do so as part of a class. They also have little interaction with the K-12 students involved with the program because their focus is to increase the K-12 teachers' knowledge of and confidence in their use of technology so that they can effectively teach this subject matter.

Another example of engineering students partnering with K-12 teachers is the work of Crumbaugh et al. [4] at Western Michigan University. Their paper highlights the achievements of students enrolled in a special section of an introductory engineering course open to engineering and elementary education majors. The semester design project requires the students to develop and build devices for use in hands-on instruction in math and science in grades K-8. This approach gives students, both engineering and education majors, an opportunity to "learn and practice engineering design, teamwork, and communication skills." However, the engineering and education students do not work directly with K-8 students.

First-year engineering students at the University of San Diego are engaged in service-learning with middle school students [Lord, 14]. The project was initiated to address the soft skills in the ABET accreditation criteria, to improve the quality of student projects and presentations, to appeal to the interests of non-traditional engineering students, to help students achieve a greater appreciation for the importance of engineering in society, and to teach diversity. The author reports strong evidence of improved team work and communication skills on the part of the engineering students. The execution of their project differs from the present work in that those first-year engineering students are required to develop and facilitate a hands-on engineering related activity of their own creation. There is also little said about the benefits to the 6^{th} grade students other than they were enthusiastic and appreciative of the opportunity, which I suspect is because they did not complete an exit assessment.

Upper-class undergraduate engineering students at the University of Colorado at Boulder have the option to complete a service learning project, quite similar to the work completed in this study, by enrolling in a general engineering technical elective course. Engineering students teach elementary school students engineering using curriculum resources from and develop a new lesson for submission to the *TeachEngineering* website. Sullivan and Zarske [16] report that their students benefit from deepening their understanding of engineering concepts, improved oral and written communication skills, and reinforcement of several ABET criterion.

IMPLEMENTATION

Course Overview

At Elon University, Challenges in Engineering (EGR 103) is the required first-year engineering course intended to teach incoming students about the engineering profession, the engineering design process, and the basic tools employed by engineers. The course is taught in two semesters and each centers on a major project. This paper focuses on the methods employed in a preliminary investigation of the impact of combining retention and recruitment efforts in a service-learning project with the first-year students in the spring semester.

Our Community Partner

We partnered with the Academically and Intellectually Gifted (AIG) program at a local public elementary school. This program serves fourth and fifth grade students who have been identified as gifted learners. They are instructed by a resource specialist in the areas of reading and/or mathematics. The school principal and resource specialist identified twenty-four AIG students to participate and their parents granted permission. Since the resource specialist knew the students best, she assigned the elementary student teams. The first-year engineering students travelled to the elementary school to engage in the activities for one hour immediately following their Friday afternoon dismissal.

Design Squad

Design Squad is a television show that airs on PBS. It is a "high-energy, high-drama reality TV that lets kids show off their smarts as they design and build working solutions for real-world clients—people who are hungry for clever ideas from a new generation of innovators." [Design Squad, 7] The creators of the show have also developed a companion website which features materials that may be used by parents to supplement at home, by educators as a teaching resource, or by mentors for community outreach. All of the materials seek to improve technological literacy and educate viewers about the engineering profession. More specifically, as outlined and explained on the website, the educational goals are to:

1. Increase students' knowledge of engineering and the design process
2. Improve the public image of engineering
3. Encourage further exploration

These goals nicely correspond to the aforementioned action items outlined in the ASEE Green Report: Engineering Education for a Changing World [ASEE, 2] and the reasons for K-12 engineering education given in Engineering in K-12 Education: Understanding the Status and Improving the Prospects [Katehi et al., 12].

Method

The Design Squad website contains a number of well-defined engineering design activities and accompanying lesson plans for children in grades 3 through 12. The Design Squad Activity Guide [8] features five engaging design challenges appropriate for afterschool programs. In addition to meeting five sessions to complete each of the challenges in the activity guide, we scheduled two days for orientation and a closing celebration. Each session was one hour long, immediately following dismissal from the traditional elementary school day. The first-year engineering students shared the roles of lecturer, elementary student team facilitator, supply gatherer, and photographer on a rotating schedule, and all assisted with the set up and clean up.

Since the first-year engineering students had no prior training in teaching, the lecturers were required to practice the presentation for an audience of their peers in the class period prior to the actual talk. We also had the necessary supplies on hand to complete the design challenge. The constructive criticism the lecturers received often led to drastic improvements in their presentations. The friendly, relaxed environment provided a perfect setting for allaying fears, calming nerves, and boosting confidence. It was also helpful for the students to have practiced the design challenges to have a clearer understanding of potential difficulties, hazards, additional needs, and outcomes.

The orientation session was critical for clearly outlining our approach and defining the project goals to the elementary school students and attending parents. The engineering students explained what engineers do in the context of the most popular engineering disciplines and explained the engineering design process in the context of a tower building hands-on exercise. This was the first opportunity for the elementary student teams to work together in this setting.

The next five meetings were devoted to the design challenges in the Design Squad Activity Guide. Each session began with an introduction of the challenge (~5 minutes) and a discussion of the relevant theory behind the challenge with the entire group of elementary school students (~10 minutes). Then, during a 30-40 minute breakout session, the first-year engineering students facilitated as elementary student teams brainstormed ideas, agreed upon a design, built it, and tested it. The competitive nature of all of the students quickly emerged as a friendly contest typically ensued during the testing period. If time permitted, we would close with a short discussion about the reasons for each design's performance.

The closing session was a fun time for all, including parents, to reflect on the experiences. Some first-year engineering students spoke about the impact of the project on their learning and all enjoyed a slide show of photographs over light hors d'oeuvres. Finally, each elementary school student was presented with a classic science-related toy to inspire continued interest.

Assessment and Outcomes

All students were assessed upon completion of the project. Rather than directly assess the elementary school students, their parents were asked to complete an exit evaluation. Evaluation questions asked about their expectations, observed evidences that the experience significantly impacted their child, and the value of this service project to the community. The first-year engineering students were asked to complete a self-assessment essay following the Integrative Processing Model (IPM) [Kiser, 13]. The IPM forces students to relate the service-learning experience to their academic and personal lives, express what they learned, and consider how the experience might be relevant in the future. The preliminary results indicate that both student groups benefitted from participating in this project.

The exit evaluations and self-assessment essays were reviewed and lists of codes were used to identify recurring themes. We received sixteen of the twenty-four elementary school students' exit evaluations back and ten of the eleven self-assessment essays back from the first-year engineering students. These small numbers made it impossible to complete a full statistical analysis of the outcomes, but provided valuable information for this preliminary study. Therefore, the numbers and percentages reported below refer to the actual number of responses received.

Impact of the Service-Learning Project on Elementary Students

In an effort to remain consistent with the current body of knowledge pertaining to the benefits of K-12 engineering outreach, the exit evaluations completed by the parents of the elementary school students were coded for the aforementioned areas in the NAE/NRC report: improved learning and achievement in science and mathematics, increased awareness of engineering and the work of engineers, understanding of and the ability to engage in engineering design, interest in pursuing engineering as a career, and increased technological literacy [Katehi et al., 12].

This preliminary study did not include any test data of the participants or assessment of the elementary students' science or mathematics teachers; therefore, there is little evidence to support that there was any improvement in their learning or achievement of science. Perhaps a longer range study could be done to assess these specific improvements. However, the following two parent responses indicate that there is potential benefit:

> "She has begun to get a better grade in science!"

> "My child's understanding of basic physical properties dramatically increased."

Parent expectations of the service-learning project were reflective of the potential benefit of increased awareness of engineering and the work of engineers. Half of the respondents (8) expected their child to learn more about the engineering profession. More specifically, they mentioned learning about the various engineering disciplines, gaining a better appreciation for solving problems efficiently, and being taught fundamental engineering concepts. When asked if their expectations were met, exceeded, or not met, all respondents stated their expectations were met (6) or exceeded (2). Representative replies from parents are:

> "This was a good experience for our daughter, and I believe she will consider engineering ideas in the future."

> "My expectations were exceeded when I saw the enthusiasm of my child and the whole group when they worked together to learn the concepts and build and put to use the models they built."

The engineering design process was explained in detail during the orientation session and the first-year engineering students reviewed it with their elementary student teams at the beginning of each design challenge session. Upon careful observation of each teams' work, I am convinced that the elementary students did have a clear understanding of and demonstrated ability to engage in engineering design. More importantly, when asked what useful skills their child developed or strengthened during this project, some parents said:

> "Problem solving and 're-thinking' or trial and error problem solving."

> "The hands-on building projects were great and helped encourage the kids to form a plan before starting to build."

> "To think about things before starting to build something."

Among all of the aforementioned parent expectations, it was evident that the parents wanted their children to explore a different area of interest or even another possible career path. Since all eight respondents indicated that their expectations were met or exceeded, it may be concluded that this service learning project did generate interest in pursuing engineering as a career. Even more convincing is the fact that one elementary student told the AIG resource teacher that this project inspired him to become an engineer. Again, a longer range study might reveal additional, more definitive support for this perceived benefit.

This research did not find any evidence of increased technological literacy among the elementary school students. However, when asked about the impact of the experience on their child, the responses (and their corresponding frequency) included that the elementary school children

- discovered that engineering and science can be exciting and fun (4)
- appreciated having college students interested in math and science as role models (2)
- continued to explore engineering and science in active play and internet searches outside of the service learning experience (2)
- strengthened their team work skills (6)
- benefitted from discovering that problem solving is an iterative process because the first idea does not always work (2)
- learned to explore more creative solutions to solving problems (9)
- realized the importance of planning (2)

While it is definitely exciting to read comments that reflect increased interest in engineering, math, and science, it is also encouraging to see that the final four items in the above list are transferrable skills.

Additionally, four parents expressed a strong expectation that their child would be or appreciation that their child was challenged. One parent wrote:

> "Our 'smarter' children are often bored in class because they have grasped materials, but all federal aid ($) and recognition goes to lower performing students 'grasping materials.' So teachers have to stop and repeat and repeat and repeat. This has [the] result of smart, motivated child[ren] BORED, and not challenged. This program was a challenge, new level of thinking, and FUN!"

Apparently, the parents of some AIG students feel that their children are being underserved. This raises an interesting point, because we received some criticism for selecting this community partner since it was perceived that neither AIG students nor the population served at that particular school needed this exposure.

The evidence presented here clearly shows that Design Squad design challenges facilitated by first-year engineering students can influence elementary students' learning and achievement in science and mathematics, awareness of engineering and the work of engineers, understanding of and the ability to engage in engineering design, and interest in pursuing engineering as a career. It is also a unique way to challenge high achieving students and facilitate further development of their critical thinking, problem solving, and team work skills.

Impact of the Service-Learning Project on First-Year Engineering Students

Comments related to the impact of the service learning experience in the first-year students' self assessment essays can also be divided into six distinct categories based on relevant literature and ABET accreditation criteria [ABET, 1]. As mentioned earlier, Strage has noted that course engagement, deepening of curricular knowledge, and civic engagement are ways in which service-learning compliments undergraduate education [Strage, 15]. ASEE has called for more emphasis on the development of soft skills, such as communication and team work, in the undergraduate curriculum [ASEE, 2]. The First Year Engineering Students identified additional soft skills that they gained or sharpened in the experience, which I have coded as transferrable knowledge and skills.

One of the reasons my colleague and I decided to include a service learning experience in the second semester of the first-year engineering curriculum was because we both noted that it was difficult to maintain the first-year engineering students' interest. Before, the fall semester featured a popular hands-on design project, while the spring semester was almost entirely lectures. By integrating the service learning project with the essential lecture material, engagement in the course and the engineering profession was improved and sustained. Here is what three students had to say:

> “I thought it was going to be dumb at first, but when we were sitting in class taking notes, I was wishing that we were at the school teaching the kids.”

> “…the Engineering 103 service-learning project with the students at Smith Elementary has been, hands down, the best experience I’ve been able to experience.”

> “The main thing that I learned about myself through this experience is that I could teach some kids about my passion, building and designing. The excitement [in] the girls’ eyes when we were building things like boats, towers, and zip lines reminded me why I wanted to be an engineer and why I love the profession.”

Deepening of curricular knowledge was one of the most frequently cited benefits from participating in this project, with seven first-year engineering students commenting. The students say it best, but to sum up their responses, they quickly realized that true understanding is found through teaching:

> “In this experience I was able to see what gaps I did have in the knowledge I had relating to the physical concepts used in the tasks given to the kids.”

> “This project really showed me that I need to study up on my physics fundamentals; I was struggling trying to explain some of the physics ideas to the students in my group.”

> “Doing this project made me realize that there were many key terms that I use every day that I could not put into words to teach someone. To fix this problem I had to do some learning myself which really helped me to better myself as an engineer and teacher. In the end this entire project made me work more than I had thought. It challenged me and increased my knowledge of not only concepts but what it is like to work in a group.”

A number of first-year engineering students had bewildered looks on their faces when the project details were explained in class because they could not appreciate the significance of our involvement with elementary students. Fortunately, those looks and thoughts quickly faded to distant memories once we got started, as one student said:

> “I think that from this experience I realized what you as teachers have tried to emphasize. That is that as an engineer we serve the public, and it is important to continue experiences like this and be involved in the community that I may eventually serve.”

Among another six responses related to civic engagement, some revealed that they enjoyed working with the younger students and others plan to seek other opportunities to do something similar in the future.

Communication was another highly recognized benefit from this service learning experience as evident by seven students’ comments. In this age of instant messaging and constant casual conversation on mobile devices, students’ everyday communication skills are rapidly deteriorating. They are even more challenged to engage in a professional or business conversation and speak in technical terms. This project helped expose some of these deficiencies and some representative student comments were:

> “It taught me how to present scientific information in a way that a non-science person would be able to understand.”

> “…I now know that it is key to have your information presentable at the education level of who ever you are presenting to. If they don’t understand what you are presenting, then it was all a [complete] waste of your time as well as theirs.”

> “…I feel as if I got a lot better at compiling and presenting information.”

Surprisingly, only four first-year engineering students mentioned teamwork in their self-assessment essays. This suggests that they did not feel they made noteworthy gains in this area. Perhaps this is due to the nature of engineering at Elon. Class sizes are small, a number of the students are in several of the same classes, and several of the students reside in an academic learning community, so they already often work together. Nonetheless, teamwork was addressed on two levels for the first-year engineering students involved with this project: they facilitated teams of elementary students and they worked together to execute the entire project. Based on his observation of the elementary student teams, one student wrote:

> "Keeping the mind open to suggestion is a very important part in a life of an engineer, and it was evident that groups worked the best when they communicated their thoughts together."

Another very assertive student's perspective regarding working with his peers demonstrates significant personal growth:

> "Focusing more on myself I gained a better understanding of what it is like to work in a group on a project where there are conflicting ideas that all could work. You need to sit back more often and try and see the project from another person's view. This allows you to be a better team player and not that person that bullies others to do it his way. With all this gained understanding I hope I will be better able to work with all types of people when I do end up entering the work place. More along the same line I honed my skills when it came to teamwork and even leadership."

Leadership, adaptability, and preparation were among the other growth areas the engineering students identified in their self-assessment essays. These are life skills that are sure to benefit them for many years to come. Here is what students had to say:

> "The main thing I learned was to be more assertive whenever I am leading something."

> "We were forced into roles that may have been uncomfortable or unusual for us, and we had to react and adapt in order to do what we needed to do."

> "I saw that I need to work on my presenting skills and public speaking in order to be successful in the future; therefore I will obviously work on this. In addition, I learned that it is very important to do a "mock" presentation before the actual event in order to work out any problems in the presentation. I never did this prior to this project and it really helped for this project."

In closing, I remind you that this was an afterschool activity that took place on Friday; a very risky endeavor indeed, but what greater reward than to have two groups of young people excited about engineering at a time when academics are typically low on the list of priorities. Here are two representative responses:

> "My child loved it and was disappointed on Fridays that were <u>not</u> engineering days."

> "It was a lot [of] fun to be able to do this, and I would definitely recommend doing this with your future engineering students!"

Potential Improvements

I am generally pleased with the way that this first Design Squad service-learning project turned out. The published materials are so well-written and well-thought that no modifications were needed to execute the project. However, upon reflection and review of the literature, there are a few changes that I'd like to implement to make it a richer learning experience for the first-year engineering students. Sullivan and Zarske [16] had the partner school teacher visit their engineering class to discuss what they should expect from the elementary school students. I agree that this is a great way to address some of the uneasiness expressed by the engineering students. Lord [14] required her engineering students to develop and facilitate a hands-on educational activity. A similar approach might be useful during the closing celebration to give the engineering students an opportunity to put their newly acquired knowledge and skills to use.

The assessment tools also served as venues for the elementary student parents and first-year engineering students to suggest improvements for the next session. The responses from both parties included allowing more time, improving classroom management (because the elementary students were quite noisy and playful at times), having more space to work, concluding each session with a closing discussion and/or supplemental materials for home use, and offering the program to more students. All of these would be positive improvements as well.

Conclusions

Issues related to recruitment and retention can be addressed in a service-learning partnership between elementary school and first-year engineering students using Design Squad design challenges. The elementary students demonstrated improved learning and achievement in science and mathematics, increased awareness of engineering and the work of engineers, understanding of and the ability to engage in engineering design, and interest in pursuing engineering as a career. The first-year engineering students reported increased engagement in the course, deepened curricular knowledge, more interest in civic engagement, improved communication skills, enhanced team work skills, and personal growth in areas such as leadership and preparedness. It has been reported by national organizations and in the literature that most of these areas must be addressed in order to tackle the greater issues of recruitment and retention. It is also clear that all of this may be accomplished with fun and enjoyment.

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