Development and Execution of a Successful Mechanical Engineering Outreach Program for Middle School Girls

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This paper focuses on the development and execution of a successful mechanical engineering outreach program for girls ages 10-13. The program featured four different hour-long hands-on mechanical engineering activities focused on robotics, biomechanics, aerodynamics and energy systems. The program was developed in partnership with the Girl Scouts of Eastern Pennsylvania and the target audience was active girl scouts in grades 4-8. The hands-on activities were developed and implemented by five full-time faculty members, two of whom were female. The effectiveness of the program in promoting engineering studies to this target audience was assessed using a survey instrument. The survey results indicate that the program was extremely effective in promoting engineering to this cohort. Prior to attending the program only 9 of 57 girls were strongly considering engineering as a career, while after the program this number doubled to 18 who were strongly considering engineering as a career with another 35 potentially considering engineering as a career.

1.0 Introduction

1.1 Why are female outreach programs in mechanical engineering necessary?

The 17.8% percent of bachelor's degrees in engineering awarded to women in 2009 was the lowest percentage in fifteen years and caps seven straight years of decline from a high of 20.9% in 2002[1]. Mechanical engineering as a discipline draws even fewer women with a scant 11.4% of 2009 degrees awarded to women[1]. However, many engineering disciplines show significant female enrollment and graduation rates. The engineering disciplines with the highest percentages of degrees granted to women include environmental engineering (44%), biomedical engineering (37%), and chemical engineering (35%)[1]. These figures are in stark contrast to not only mechanical engineering (11%) but also computer engineering (8%) and electrical engineering (11%)[1]. Thus the question arises: why are some engineering disciplines more successful at attracting and retaining female students?

Research has shown that there are several key steps to recruiting and maintaining female enrollment in engineering. A 2008 National Academy of Engineering report *Changing the Conversation* concluded that the field of engineering as a whole needs to promote itself as strongly connected to making a difference in the world[2]. This theme is found to appeal greatly to all students, but resonates particularly well with female students, as well as African American and Hispanic men[3]. This approach is in contrast to the more typical media depiction of engineers as focused on math, science and computer applications to the exclusion of the world around them.

The next generation of mechanical engineers will face extreme challenges in the need to develop new energy sources, modes of transportation and health care technology, and in the need to lead the development of emerging countries in a sustainable and effective manner. Surveys of middle and high schools girls have consistently shown that they are drawn to careers with a strong "helper" or "outreach" aspect[4,5], and the high female enrollments in the engineering disciplines most closely tied to this "helper" image (environmental, biomedical, chemical) continues to reinforce this idea. Thus, if mechanical engineering is going to effectively promote higher female enrollments it needs to promote the societal and environmental influence of a career in engineering. This message should also have a beneficial impact on minority enrollment while not negatively affecting white male enrollment.

Villanova University, an Catholic university founded by the Augustinian order of priests in 1842, has a long standing tradition of community service and outreach with an Augustinian vision of people living in community united in "mind and heart" in the ardent search of Wisdom. This tradition is manifested in the University's mission statement which explicitly encourage students, faculty and staff to engage in service experiences and research, both locally and globally, so they learn from others, provide public service to the community and help create a more sustainable world; and to commit to the common good, and apply the knowledge and skills of our students and faculty to better the human condition. This tradition of service and outreach is interwoven through the mechanical engineering curriculum and the Mechanical Engineering department at Villanova has historically enrolled women at much higher rates than the national average of 11%. Over the past five academic years (from 2005-06 to 2009-10), Villanova has awarded 312 BSME degrees, of which 64 have been awarded to women (20.5%). The enrollment each year in

that time span has ranged from 15%-25% female. Thus it is our experience that the service and outreach emphasis will attract a diverse enrollment.

The influence of a mentor is also found to have a significant impact on the career choices of young women[6,7]. A pre-college interest in math and science is often not enough to entice young women to select an engineering major, but the presence of a catalyst in the form of external encouragement often does lead a young woman to select an engineering major. This encouragement is found to be effective when received from a wide variety of sources including family members, teachers, or even simply an engineer that they recently met[6]. The lack of female role models in engineering works against this necessary catalyst[7].

Finally, it is known that middle school is the most crucial time to engage young women in math and science. In 4th grade, girls and boys report the same level of interest in math and science classes as boys, but by 8th grade boys are found to be twice as interested in math and science[8]. If a girl loses interest in math and science during the middle school years, she is unlikely to pursue higher-level math and science courses in high school and will not select an engineering career[9]. Thus, it is critical to address this drop in interest in the middle school years by engaging young women through both curricular revision and outreach programs that draw them into engineering careers.

1.2 Target goals

The goals of this outreach workshop were to create a multipronged approach to female engineering recruitment, using the thematic approach of "making a difference in the world" as suggested by the National Academy of Engineering, providing female engineering role models and mentors, and engaging middle school girls in math and science.

The one-day workshop was targeted at girls ages 10-13 with a theme of "Mechanical Engineering: Solving Problems, Changing Lives." The workshop activities were designed to address the positive societal and environmental impact of mechanical engineering careers. The overall program was led by Dr. Amy Fleischer, an Associate Professor in Villanova's Mechanical Engineering department. The individual activities were developed and ran by other mechanical engineering professors, both male and female with strong interests in outreach activities. Finally, female and male Villanova students associated with the College's Engineers Without Borders group also provided assistance, thus tying together mentorship with outreach and positive social impacts.

1.3 Target audience/GSEP partnership

The target audience for this program was girls in grades 4-8 (ages 10-13). Rather than partnering with a particular middle school, it was decided to reach out to as broad an audience as possible. As Villanova is located in the Philadelphia metro region, this meant contacting potentially hundreds of public and private schools. To handle this task more efficiently, the team partnered with Girl Scouts of Eastern Pennsylvania. Girl Scouts of Eastern Pennsylvania (GSEP) is a

division of Girl Scout of the USA (GSUSA) and serves over 41,000 girls ages five through 17 in nine Pennsylvania counties[10].

GSUSA is a natural partner for developing science, technology, engineering and math (STEM) programming for girls. GSUSA has long been a strong advocate for hands-on science and engineering programs for girls, through both its traditional badge activities and strong partnerships with industry and government advocates of STEM activities. Over the past15 years GSUSA has developed major STEM initiatives with NSF, NASA, Lockheed Martin, Motorola and First Lego League[11].

GSEP was an enthusiastic partner in this activity in promoting the outreach program to their entire membership. The GSEP registration quickly exceeded the original target enrollment of 60 girls, so a waiting list was developed. The Villanova team decided to open the registration to 80 girls to accommodate those on the waiting list, and the final registration was 80 girls accompanied by 34 adults. GSEP handled all of the promotion and registration activities while the Villanova team handled the program development. The cost of presenting the day's activities were covered entirely by Villanova through a grant received from Air Products Corporation. The girls were charged a nominal $5 fee to participate, which went entirely to GSEP to cover administrative costs.

2.0 Program design

2.1 Overview of day

The day was designed to give the girls an overview of the wide variety of topics within mechanical engineering, and allow them to explore several of these topics through hands-on activities. The activity topics were selected to highlight beneficial environmental and societal aspects of engineering and included alternative energy systems, biomedical design, aerodynamics/fuel efficient design, and water distribution for third world countries.

The day began with an introduction to mechanical engineering given to the entire group in attendance by Dr. Fleischer. This introduction explored the idea of engineering, the engineering disciplines and an overview of the different aspects of mechanical engineering, including the ways in which mechanical engineers "change the world" through their research, designs and product development. The girls also heard from a recent female engineering alumnus who spoke on her experiences at school and in industry and were welcomed by the Villanova Mechanical Engineering Department Chair, Dr. C. Nataraj.

The girls were then divided into four smaller teams of 20 for the hands-on activity periods. Each team was led by two engineering students who remained with the girls for the entire day. The students answered the girl's questions and assisted in the activities. Each of the four activity periods was an hour in length, with two activity periods before lunch and two after lunch. Each activity was designed and led by a full-time Villanova Mechanical Engineering faculty member. Every team rotated through each activity over the course of the day.

The day concluded with a wrap-up session for the entire attendance in which the girls completed assessment surveys and listed to a short talk by the student president (a female student) of the Villanova Engineers without Borders group.

2.2 Solar energy activity

Environmental science is of great interest to many young women and environmental engineering currently has the highest rate of engineering female enrollment (44%)[1]. Through its historical emphasis on energy systems, mechanical engineering is on the forefront of the development of alternative sources of energy to mitigate the environmental impact of fossil fuels. Thus, Dr. Aaron Wemhoff developed an activity period focused on alternative energy systems to showcase this environmental emphasis within mechanical engineering.

Solar energy represents one subset of alternative energy with relatively mature and inexpensive technology (e.g. photovoltaics and solar collectors), so educational demonstrations are readily available. Therefore, the goals of the activity were (1) to introduce the girls to concepts of alternative energy, (2) to demonstrate the amount of energy that is available from the sun, and (3) to demonstrate the applications of solar energy harvesting in the form of electrical conversion (photovoltaics) and thermal conversion (solar collectors).

The activity period began with a fifteen-minute presentation introducing the concepts of alternative energy and solar energy. The presentation briefly described energy types, energy conversion, fossil fuels, alternative energy, and solar energy. The presentation, designed towards a middle-school audience, was highly interactive to maintain the group's attention.

After the presentation, the girls proceeded outside the building to an area open to direct sunlight to continue the activity. The 20 girls were split up into four groups of five, each led by an undergraduate Mechanical Engineering student. A safety briefing was provided, and all girls were provided with sunglasses. The undergraduates led the girls in three activities:

1. Assembly and demonstration of photovoltaics part 1: Educational solar demonstration kits from Silicon Solar, Inc., each containing photovoltaic and load (fan or an LED), were assembled by the girls into a simple circuit containing a direct connection between the photovoltaic and the load. The Villanova students then demonstrated the circuit by showing the orientation of the photovoltaic to the sun affects the load.
2. Solar collector activity: Four 20x magnification shaving mirrors and four digital meat thermometers were used to demonstrate the ability of solar collectors to produce heat. The steel tips of the steel thermometers, painted black to increase absorptivity, were placed at the focal point of the mirrors to collect solar radiation (See Figure 1). The resultant solar collection increased the thermometer temperature to values exceeding 300°F.
3. Assembly and demonstration of photovoltaics part 2: The students helped the girls assemble Solar Grasshopper kits from Silicon Solar, Inc. Each girl was provided with a kit featuring a photovoltaic connected to a motor (See Figure 1). When the photovoltaic was exposed to the sun, the running motor caused the grasshopper to "buzz" and randomly move about.

The girls enjoyed the activities and learned a great deal about solar energy. At the end of the activity, the query "Did you learn something today about solar energy?" received an overwhelming positive response. In addition, when asked the open-ended question "What did you learn today?" most answers pointed to the amount of heat produced by solar collectors and their surprise at the ability of the sun to produce electricity.

Figure 1. (left) Concentrating solar mirror experiment. (right) Successful build of a solar grasshopper .

2.3 Bioengineering Activity: Designing a Prosthetic Lower Leg

The interest of young women in "helper" careers drives a significant female interest in both medicine and biomedical engineering. Female enrollment in medical school now exceeds male enrollment[12] and biomedical engineering student enrollment is 37% female[1]. However, not all universities offer biomedical engineering at the undergraduate level, and the broad background of a mechanical engineering degree is a popular route to graduate studies in biomedical engineering. A biomedical activity was thus chosen to promote this emphasis within mechanical engineering. Dr. Ani Ural developed an activity focused on prosthetic lower leg design to illustrate how traditional mechanical engineering principles can be interfaced with biological sciences.

The prosthetic leg activity began with a five minute presentation on biomedical engineering and what biomedical engineers do. In addition, the presentation introduced the desired engineering qualities of a prosthetic leg (strength, stability and comfort) and contained an overview of many successful prosthetic leg designs.

Following the presentation, the girls were divided into five groups of four. Each group was provided with the materials to use in building a prosthetic lower leg: one mailing tube of size 2 in x 24 in, a flattened cardboard box (4 x 4 x 4 in), duct tape, strings, rubber bands, bubble wrap, sponge, and foam plates. The girls were also provided with scissors, ruler, pens, and paper.

After receiving the materials, each group was asked to draw a concept design for their prosthetic leg. Following the completion of their initial drawings, they selected one member of their group for whom they designed the prosthetic leg. They took measurements on the selected member of the group and cut the mailing tube to fit that person's lower leg. Using the materials that were given to them, each group designed a prosthetic leg based on strength, stability and comfort criteria. The girls also had to design a connection to attach the prosthetic leg to the knee of the person who was going to wear it. The girls were given 40 minutes to complete their designs.

The last 10 minutes of the activity was dedicated to the evaluation of the design made by each group. Each group presented their design to the entire class including how they used each material and how each material contributed to the design (See Figure 2). Following the

presentations, they demonstrated how the selected girl could walk with the designed prosthetic leg (See Figure 2).

Every group was able to successfully design and fabricate a prosthetic leg design using engineering concepts of strength and stability in their designs. Also, some groups modified their original design once they realized that the prosthetic leg was not stable or not strong enough, which enabled them to understand the design process in engineering.

Figure 2. (left) Presentation of final prosthetic design (right) demonstration of successful use of prosthetic

2.3 Water Distribution Activity

The design of gravity fed water distribution systems for impoverished villages in third world countries ties together both the interest of young women in "helper" careers and in environmental science and engineering. "Engineering has a direct and vital impact on the quality of life for all people" according to the Preamble of the National Society of Professional Engineers Code of Ethics[13] and according to the American Society of Mechanical Engineers, engineers should use their knowledge and skill for the enhancement of human welfare.[14] Prof. James O'Brien selected the topics in this water distribution activity to introduce the girls to this human welfare aspect of mechanical engineering and designed the activity such that the girls would understand that engineers have a responsibility to improve society. The project also introduced a number of core technical concepts including fluid flow and pressure loss in a system, torque and angular momentum, the use of pumps, and the design and interaction of motors and gears.

The water distribution activity began with a brief video about the lack of clean water in some third world communities followed by a five minute presentation on the design of gravity fed water systems to address this issue. The girls were then assigned to smaller teams. Each team then organized themselves into a “water committee” and a “transportation committee”.

The “water committees” were assigned the task to get water from mountain springs (buckets of water with pictures of springs pasted on them) to community water storage tanks (smaller plastic containers attached to pictures of villages in Central America). The water then had to be pumped from the “community water storage tanks” into a portable storage tank (plastic water bottle) at a higher elevation to be transported by a Lego car and trailer to another “community”.

In order to perform their tasks, the girls had to connect different pieces of tubing without leaks (See Figure 3). They had to adjust the elevations of their water tanks so the water would flow from the source into the tanks at a reasonable rate while still being as close as possible to the “community”.

The “transportation committees” built the Lego cars and trailers (see Figure 3) and tested them for durability, strength, and steering. The Lego motors were not strong enough to pull the water bottles without proper gearing. The filled water bottles from the “water committees” were loaded onto the Lego trailers and towed to the specified location. Selected girls from the “transportation committees” were trained and then assigned the task of teaching the other girls how to use tachometers.

In most cases the groups completed the tasks in the one hour allotted to them. All groups completed the water components of the project. Some groups needed help building and testing a Lego car and trailer robust enough to move the water container to the other location. All girls actively participated in the activities and they seemed interested. They were excited when they were able to complete the tasks.

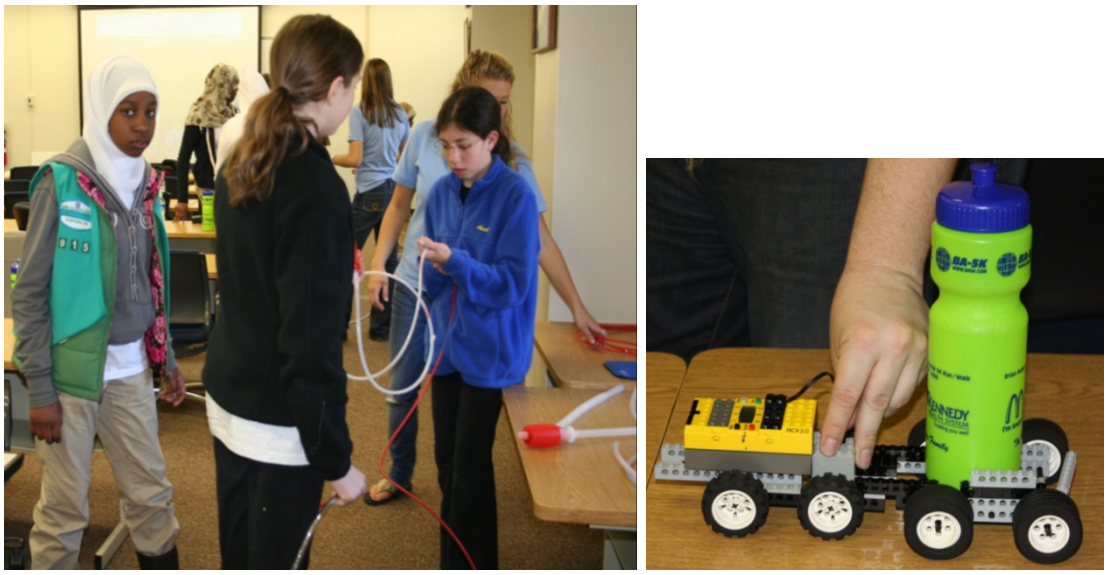

Figure 3. (left) The Water Committee works on the piping system. (right) The transportation committee’s water trailer system.

2.4 Aerodynamic Activity

The final activity focused on energy efficiency, with Dr. LeRoy Alaways linking environmentally friendly design with traditional mechanical engineering topics this time through the aerodynamic design of vehicles.

The aerodynamic vehicle activity began with a five minute presentation on aerodynamic design, including a discussion on designs that reduce drag and the benefits of a low drag vehicle. Following the presentation the girls were again divided into five groups of four. Each group was provided with the materials to design an aerodynamic vehicle. The vehicles in this case were balsa wood sliders which would travel a zipline. The zipline exited from a 4th floor building window and ran to the ground below. Under no circumstances were the girls allowed near the open window.

Each team of girls was provided with a large balsa wood block. Using the information in the initial presentation, the girls were asked to select their block's cross section (1" square, 2" square, 3" square or 4" square) and length (12" – 36"). The girls were also provided with lightweight saws and sandpaper to shape the blocks into the desired shape, along with Styrofoam cones and hemispheres as well as glue and paper which could be used to alter the shape of the vehicle. The girls designed and built their vehicles taking into account the lesson on aerodynamic drag (see Figure 4) and the professor in charge helped the girls drill holes into the block in which eyebolts were installed to suspend the vehicle from the zipline.

Once all vehicles were complete the college student leaders took the girls downstairs and outside the building to the bottom of the zipline. The professor remained in the classroom and sent each vehicle in turn down the zipline (see Figure 4). The travel time for each vehicle was timed with a stopwatch and recorded. The teams then returned to the classroom to discuss the results. The last 10 minutes of the activity was dedicated to the evaluation of each design and its performance on the zipline. Every group was able to successfully design and fabricate a zipline vehicle and then evaluate their performance in comparison to other designs, based on time and shape.

Figure 4. (left) Design and build of aerodynamic sliders. (right) Test of a slider down the zipline.

3.0 Analysis of Outreach Effectiveness

The effectiveness of this outreach workshop in meeting its target goals was assessed primarily using a survey instrument. Of the 80 girls who registered for the workshop, approximately 70 showed up the day of the workshop, and 57 turned in completed surveys at the end of the day. As discussed earlier, the target goals of this workshop were:

- Provide engineering/math/science outreach to middle school girls
- Use the approach of "making a difference in the world" as hook to interest young women in engineering activities
- Provide engineering role models and mentors

The workshop was effective in providing engineering/math/science outreach to the targeted audience. The partnership with Girl Scouts provided a large audience for promotional purposes, and the workshop had to be expanded from the original 60 seats to accommodate the interest level. Because of the multi-age nature of some Girl Scout troops, a few younger girls attended. Also, as some middle schools begin in 5^{th} grade and others in 6^{th} grade, there was a wide variety of grade levels. The girls completing surveys identified their grades as follows: 4^{th} grade: 2 girls, 5^{th} grade: 22 girls, 6^{th} grade: 23 girls, 7^{th} grade: 1 girl, 8^{th} grade: 9 girls. The workshop was also effective at providing engineering role models and mentors with participation from five full-time faculty members, two of whom were female, one female alumna and 13 students, four of whom were female.

The workshop activities and the framework of "making a difference in the world" did engage the girls and hold their interest level. The girls ranked each activity according to their interest level as seen in Figure 5. The solar energy activity received extremely high levels of interest with 37 girls reporting that they "loved it" and other 13 "enjoyed it" for a total of 50 of 57 girls expressing high interest levels. In fact, the girls expressed high levels of enthusiasm for all the activities with the top two ratings ("loved it" and "enjoyed it"). These two ratings were selected by 49 girls on the water distribution project, 46 on the aerodynamic vehicle project and 42 girls on the prosthetic leg project. Thus even the lowest ranked project had 73% of all the girls reporting high interest levels. No more than 1 or 2 girls ranked any project in the lowest interest category.

The girls' interest levels were also assessed by asking them if they would recommend this workshop to a friend. When asked this question, 41 of 57 girls agreed that they would recommend it to a friend, and none of the girls indicated that they would not recommend it (see Figure 6). 14 of the girls were unsure if they would recommend it to a friend. Some of the girls' comments to this question shed some light on their uncertainty here: "All my friends are already here" and "My other friends are too old for this workshop". In support of recommending the workshop were the comments "I had lots of fun inventing", "I learned lots of things I didn't know before," and "I felt creative".

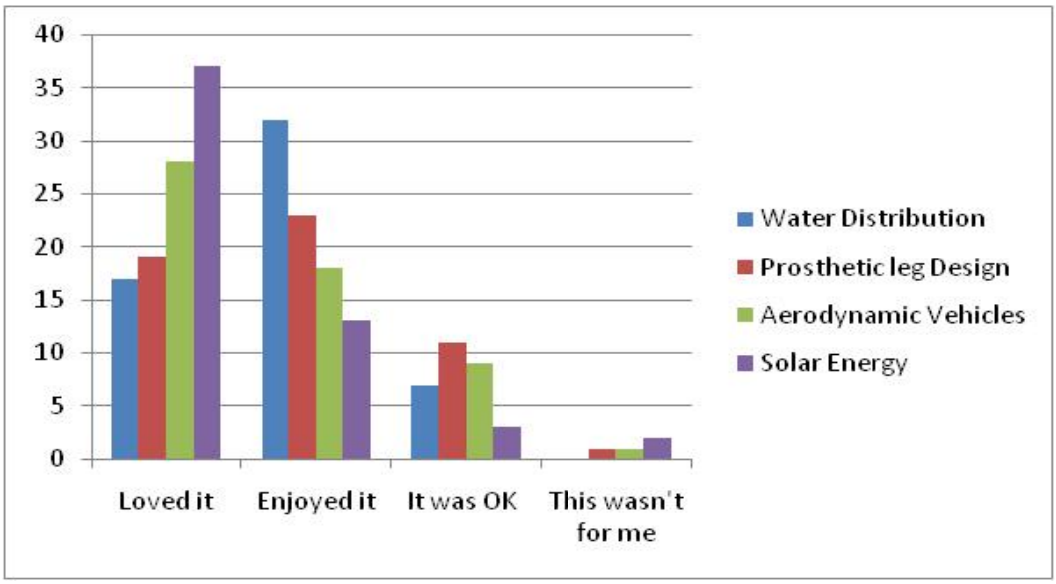

Figure 5: Assessment of Girls' Interest Level in Activities

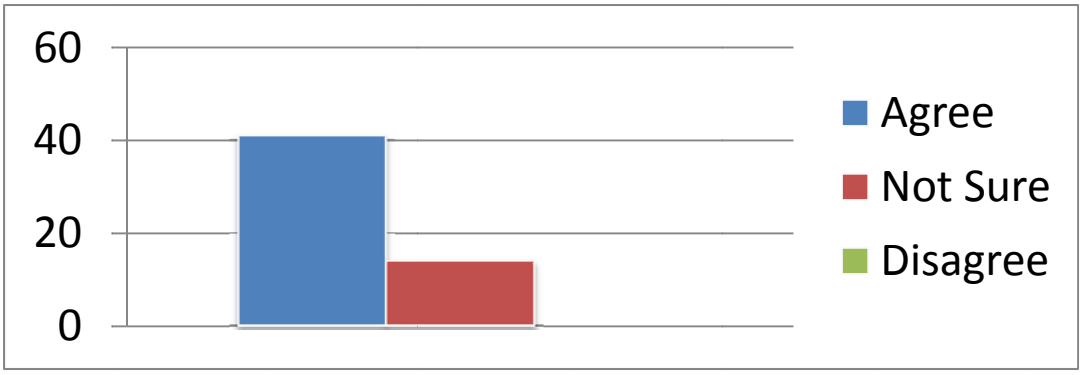

Figure 6: Would the girls recommend this workshop to a friend?

Figure 7 shows the results from two questions intended to gauge how the girls assess their own capacity for critical thinking and creativity, as both are important skills for success in engineering. During the workshop the girls were asked to assess their designs and support their design decisions. Figure 7 shows that the majority of girls feel comfortable in this role. When asked if they can explain the decisions that they make, 70% (40 girls) stated that they can do this all or most of the time, while none of the girls stated that they could "almost never" or "never" justify their decisions. A comparable number of girls (38) also stated that they could think of ways to improve what they are doing, with a very high percentage indicating that they can do this "always" (31%). However, a few girls did indicate that they can "almost never" or "never" think of ways to improve what they are doing, so this indicates some room for improvement on this topic in future workshops.

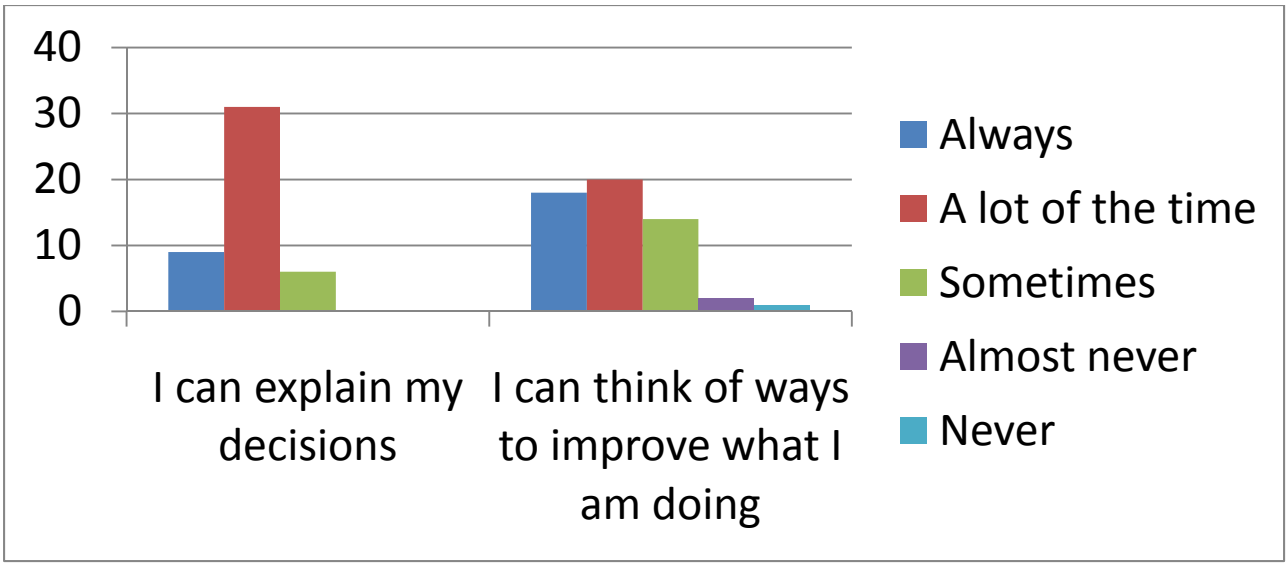

Figure 7: Assessment of Girls' Ability to Support Design Decisions and Rework Designs

While the previous data all shows that the girls enjoyed the activities, will this really translate into higher professed interest in engineering studies and careers? Figure 8 shows the change in the girls' opinions of an engineering career both before and after the workshop. When asked if they were considering a career in engineering before the workshop, only 9 girls indicated that they were, while 29 indicated that they were not. However, after the workshop, the number of girls definitely interested in an engineering career doubled to 18, while the number who were definitely not considering engineering dropped to three. The remaining 35 would "maybe" consider engineering. By any measure, a doubling of the number of young women interested in engineering is a successful workshop outcome.

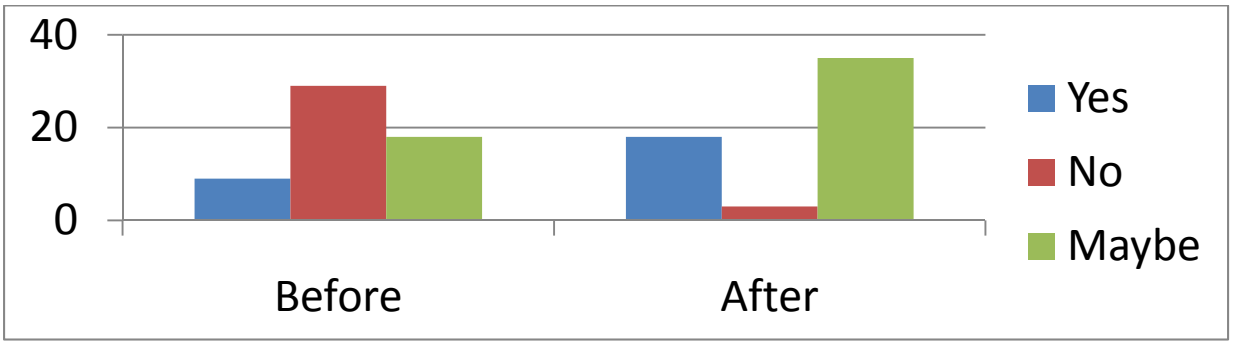

Figure 8: Number of Girls interested in Engineering Careers Before and After the Workshop

4.0 Conclusions

A successful mechanical engineering outreach program was held for girls in grades 4-8. The program featured four different hour-long hands-on mechanical engineering activities focused on the theme "making a difference in the world". This theme was executed in each activity through either the idea of environmentally friendly designs (solar energy, aerodynamic vehicles) or the idea of engineering as a "helper" career (such as medicine) through biomedical device design, and water distribution to third world countries.

The effectiveness of the program in promoting engineering studies to this target audience was assessed using a survey instrument. The survey results indicated that the program was extremely effective in promoting engineering to this cohort. Prior to attending the program, only 9 of 57 girls were strongly considering engineering as a career, while after the program this number doubled to 18 who were strongly considering engineering as a career with another 35 potentially considering engineering as a career. All of the activities were highly rated by the girls, and their self-assessed abilities in justifying their design decisions and in reviewing their designs for improvements were high.

5.0 Acknowledgements

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