Improving Skills and Attitudes in Minority Females Training for Engineering and Technology Careers

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Abstract - The authors were given the opportunity to develop a summer enrichment program for students from a large urban school system. The students involved were predominantly minority, were all from low socio-economic status households, and the majority were female. The students were selected for the program based on assessed potential for success in Science, Engineering, and Technology programs. However, pre-course testing indicated a shortfall in basic math skills necessary for such careers. Additionally, the students showed a significant lack of self confidence in their abilities to perform in math and science related subjects. This was particularly true among the young women. The month long program took the approach of connecting real world applications of simple engineering concepts to the basic math necessary to analyze those concepts. The curriculum allowed the students to explore how math relates to their world through principles that they encounter in their everyday lives. The results have been very positive both in terms of improvement in math skills, and in the student’s confidence in their ability to succeed in engineering careers. This paper will present both quantitative and qualitative results documenting the improvement in both skills and attitudes. It will also discuss the general approach taken during the development of the course and will give specific examples of subject matter which seemed to connect most strongly with the students.

Introduction

Lauren had been selected for Purdue University’s Science Bound program for inner city middle and high school students because her test scores and her teachers both indicated high potential for a career in science or engineering. However, if you asked Lauren about her view of her chances, she gave a different answer. On the first day of the Science Bound summer camp, she took a pre-class assessment test. In the middle of the test she stopped and signaled for the instructor to come over. Lauren pointed to the portion of the test that dealt with simply pulleys and levers and told him, “This is physics, I can’t do physics.” Through the first couple days of the class, it became obvious that Lauren had very little confidence in her abilities in math and science, the fundamental building blocks of an engineering career.

This is just one example of why minority females continue to be significantly under-represented in collegiate Engineering and Technology (E&T) programs. As Sean Cavanagh (2005) wrote in Education Week, “Studies show that girls have less confidence
in their math and science abilities, and take less enjoyment from those subjects, than their male peers. Those self doubts emerge despite the fact that girls, on average, consistently receive higher grades than boys in both math and science.” A multi-university study of females in engineering programs indicates that this confidence issue persists into college, and that women who leave collegiate engineering programs consistently identify low self confidence as a major barrier to completing their engineering degree. (Marra, 2004) The Center for Pre-College Programs states “Research has shown that young women still avoid advanced mathematics and science related courses and careers because they underestimate their capability and not because they lack competence or skill.” (Cano, 2004)

Statistics show that minorities (Gibbons, 2004) and females (Chen, 2005) continue to be hugely underrepresented in most engineering fields. A number of universities and secondary school systems are addressing this diversity issue by working closely with interested students during the middle school and high school years. (Usselman, 2004) The Purdue Science Bound program was created to address this disparity. Middle and high school students are selected from the Indianapolis Public Schools (IPS) System. This 40,000 student system is comprised of mostly low socio-economic households, to the extent that 80% of the students qualify for free or reduced cost lunch programs. Students qualify for Science Bound based on statewide assessment test scores and teacher recommendations. If they stay with the program through all four years of high school, they can earn a tuition scholarship to any science, engineering, or technology program at Purdue.

Your authors had the opportunity to develop and teach a month long summer program for students in the Science Bound program. Across the last two years the students in this summer activity have been over 80% minority and over 50% female, so this has been an opportunity to work closely with a truly underrepresented population, when it comes to engineering careers.

The Approach
Your authors each spent over 25 years in the aerospace industry in various technical roles before changing careers to teaching. One is currently an Assistant Professor in Mechanical Engineering Technology for the Purdue School of Engineering and Technology at the Indiana University / Purdue University at Indianapolis (IUPUI) campus. The other is a middle school math teacher at one of the IPS magnet schools as well as an adjunct faculty member at IUPUI. Both agree with Stephen Kuyath (2004) that “high school students must be ‘turned on’ to engineering and engineering technology. They need to get involved in fun and engaging engineering related activities that relate to their everyday lives.” Your authors thus began to develop an approach that they refer to as Mathematics with Real World Correlation, in which simple engineering concepts that students use in their everyday lives (usually without realizing it) are investigated and explored along with the associated mathematics concepts required to correctly model or analyze them.
In this approach, it is necessary to make sure that student involvement is a key part of every activity. Initially this approach was taken in the belief that it would keep the student’s attention better, as well as helping the more kinesthetically oriented learners. However, it turned out to be a huge benefit for the females in the class. As the Center for Pre-College Programs (Cano, 2004) has found, “‘doing rather than viewing’, is the best methodology for all students, but especially for girls who tend not to have as many opportunities or to be as encouraged as boys to work with their hands, use tools, equipment, or any type of scientific apparatus.” Additionally, as Lynda Wiest (2001) indicated in an article in *Mathematics Teacher* magazine, girls and women need to see the relevance of subjects to their own lives.

**Year Number One – Simple Mechanics**

The first year of the summer program was made available for Science Bound students between their freshman and sophomore years in high school. The class focused on exposing students to simple mechanical systems involving mechanical advantage, friction, force vectors, and structural characteristics. These are concepts that normally would not be encountered by these students under Indiana standards. However, the concepts were ones that students encounter in everyday life. Here are a few examples:

1. **Mechanical Advantage:** Students use mechanical advantage all the time, but they do not recognize it by that name. In simplest terms, mechanical advantage is achieved any time we use a mechanical system to amplify our applied effort to give it greater effect. As an attention getter, on the first day of the discussion, a demonstration was conducted. The largest boy in the class was asked if he could move a heavy desk. After he admitted that it was too heavy, a simple mechanical jack was placed under the desk, and the smallest girl in the class then successfully lifted the table with ease. The point was clearly made that mechanical advantage could make the girls as strong as the boys. This concept appeals greatly to girls while they are at an age where they do not wish to appear unable to do things that their male counterparts are able to do. The demonstration paved the way for introducing more mechanical advantage concepts, such as that supplied by pulleys, or common hand tools such as pliers, wire cutters, vice-grips, etc. The mathematics necessary to model and determine the advantage gained is not difficult. In college classes these problems are likely to involve equations of equilibrium, summing force and moment vectors, and solution of simultaneous equations. However, if the systems are kept simple, it is possible to use easy ratios and basic algebra to analyze simple systems like the mechanical jack shown in Figure 1. These are math skills that high school students should know, although they are often underdeveloped.

2. **Friction and Vectors:** Friction and vectors do not hold a lot of interest outside the classroom for many of these students. However, their soon-to-be-earned driver’s license is something that interests them a great deal. Thus introducing the concept of a friction circle, as shown in Figure 2, holds some appeal. It can be used to determine how fast a car is capable of going around a corner, rather than ending up in the ditch. This makes the subject more interesting to high school freshmen, many of whom are on the verge of obtaining their first license.
3. Structural Concepts: Building balsa wood bridges has become a staple of pre-engineering summer camps. There would be no point in discussing another such project, if students were simply given wood strips and glue and turned loose to build. Instead, during this class, students began with an examination of the structural merits of different pieces of balsa. They were given 12” long balsa beams of 1/16”x1/16”, 1/8”x1/8”, 1/16”x1/8”, 1/16”x1/4”, and 1/8”x1/4”. Each beam was placed spanning the space between two tables and secured at both ends with duct tape. A paper cup was hung from the center of the beam and weight of some kind (e.g. sand, pea gravel, marbles, etc.) was added to the cup until the beam failed. By loading beams of different dimensions and orientations (i.e. horizontally oriented cross-section versus vertically oriented cross-section), then weighing the load that caused failure, students can ascertain not only which beams and orientations are better, but can also develop the relationships telling how much better. Additionally, the students are given the opportunity to examine simple rectangular frames versus different triangular frames to see which ones support the most load. Only after these investigations were complete did they begin their construction project. Students self-selected into two person teams which turned out to be almost exclusively two males or two females. The approach described above appeared to benefit the females much more than the males. When teams immediately dove into building, the boys tended to launch off with confidence, while the girls doubted their own ability to design and build competitive structures. However, when the data gathering and investigation became a part of the project, the girls gained confidence, feeling that they knew enough to compete with the boys. Because they saw the advantages of this experience, they also tended to learn more from it than the boys who wanted to rush in and get started. Thus in the end, the females frequently came up with better designs than the males.
Year One Results
The instructors expected a comparison of the pre- and post- class assessments to show a notable gain in the areas of engineering concepts. However, the gain in math skills was perhaps more significant, as shown in Table 1. This indicates that such connective plans of study may be key to preparing minorities and females for success in engineering or technology programs. Even more important was the qualitative increase in self confidence. By the end of the course, the females showed at least as much confidence as the boys, despite starting far behind in terms of self belief. A good example would be Lauren, the young lady discussed in the opening paragraph. By the end of the month she turned out to be one of the top students in the class despite her early self doubts. On the final day of class, when reminded of her initial comment, she gave one of those confident smiles that makes a teacher feel like their job is truly worthwhile. Lauren left the class with increased confidence that she could succeed, as did most of the students. And succeed they did, as 67% of them showed GPA increases in the semester that followed the class.

Table 1 – Results of Pre- and Post- Class Assessment Test Averages from Year One

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Pre-Class</th>
<th>Post-Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Mechanical Advantage</td>
<td>8%</td>
<td>12%</td>
</tr>
<tr>
<td>Friction</td>
<td>32%</td>
<td>45%</td>
</tr>
<tr>
<td>Structural Mechanics</td>
<td>6%</td>
<td>10%</td>
</tr>
<tr>
<td>Algebra</td>
<td>61%</td>
<td>61%</td>
</tr>
<tr>
<td>Ratios</td>
<td>81%</td>
<td>90%</td>
</tr>
<tr>
<td>Geometry</td>
<td>53%</td>
<td>36%</td>
</tr>
</tbody>
</table>

Overcoming the student’s belief that they cannot do something is a huge first step when working with minorities. It is doubly important, when dealing with minority females as young women are much more likely to give up on problems that they think are too difficult for them. (Liao, 2005) Research has shown that women also tend to accept that some things are simply too hard for them, rather than trying to overcome any shortcoming by improving skill level. (Dweck, 1999) For these reasons, the gain in both skill level and self confidence seen in the first year of the author’s program gave good cause for optimism. A teachers guide for this module will be available from the authors at the conference.

Year Number Two – Environmental Engineering
Two major changes occurred for the second year of the summer program. It was enlarged to include students between their sophomore and junior high school years as well as those between freshman and sophomore years. Since the potential existed for some of the first year students to sign up a second time, the instructors had to prepare by
designing a second module. As it turned out, half of the older group in year two were girls who had been part of the first year class. It appeared that they enjoyed the confidence boost achieved during the previous summer, and wanted more. The second change was that the assessment test was enlarged to include a section aimed at measuring any change in attitudes, including self confidence, from the beginning to the end of the class.

The first year students participated in essentially the same module on simple mechanics as previously described. The second module was completely new, and it took a different approach. A number of articles have recently been written about the fact that women tend to seek careers which offer opportunities to make a difference in society. Too often, engineering is not seen that way. For these reasons, the new module focused on sustainable engineering and environmental impact, both of which address societal concerns. These topics were covered as follows:

1. Environmental Footprint: The students conducted an investigation of the environmental footprint created by the use of one of their favorite devices; the cell phone. This involved learning the process by which cell phone circuit boards are made, and the toxic waste byproducts that result. The students conducted chemical experiments on dilution, metal extraction from waste water, evaporative processes, and even built and tested their own miniature landfill. Consistent with the authors’ Mathematics with Real World Correlation approach, these topics were always tied closely to the necessary mathematics, whether in determining dilution concentrations, balancing chemical reactions, or extrapolating laboratory sized experiments to approximate the quantities necessary to produce an entire city’s worth of cell phones.

2. Civic Involvement: After the environmental footprint activities were concluded, the students were presented with a scenario in which they lived in a small town where a new chemical plant was planning to be located. The plant was going to be involved in the chemical processes they had just examined. Students had to weight the consequences of the new company coming to town. On the one hand it was the cure to high unemployment and dwindling tax base for the hypothetical town. On the other hand were the environmental impacts that they had just studied. They split into two sides, pro- and con- relative to the coming of the new company. Both sides had to research and prepare an argument to present to a simulated town council meeting supporting their position, for or against, the new plant. All the students in the teams became involved in this activity, but the young women were particularly passionate about the task. They poured themselves into the effort and by the day of the pretend town council meeting, both sides had very persuasive arguments to present. A complete description of the environmental footprint module is available through Indiana’s Portal Resources for Indiana Science and Mathematics (PRISM) website, www.rose-prism.org. (Otoupal, 2005)

Year Two Results
Once again, the skill levels of the students increased between the pre- and post- class assessments, including some new categories which were added the second year, as shown
in Table 2. The lesser increase in gains in female scores for the first three categories is attributed to the fact that the majority of the second year females were in the Environmental Engineering group and not the Mechanical Advantage group.

Additionally, the attitude related questions, scored on a Likert scale of 1 to 5, gave some valuable input. The largest changes for any of the 15 attitudinal statements were an approximately 40% improvement for females (25% for males) associated with the two similar statements: “I’m afraid I will have a hard time with Math in college” and “I’m afraid I will have a hard time with Science in college.” A positive gain was also seen relative to the statement “I believe I could be a good engineer.” Apparently, the involvement of the students in these two summer courses had made a positive difference in both their skills level and their belief in their own ability to succeed. Once again Lauren serves as an example of progress made. When she left at the end of the second summer class, she was no longer certain what she wanted to study when she ultimately headed for Purdue. Originally she was interested in a career in medicine. However, after these interactions, she was thinking about investigating some of Purdue’s engineering opportunities before making up her mind for sure.

Table 2 – Year Two Results of Pre- and Post-Class Assessment Test Averages

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Pre-Class</th>
<th>Post-Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Mechanical Advantage</td>
<td>30%</td>
<td>16%</td>
</tr>
<tr>
<td>Friction</td>
<td>50%</td>
<td>33%</td>
</tr>
<tr>
<td>Structural Mechanics</td>
<td>17%</td>
<td>6%</td>
</tr>
<tr>
<td>Algebra</td>
<td>80%</td>
<td>60%</td>
</tr>
<tr>
<td>Ratios</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>Geometry</td>
<td>70%</td>
<td>16%</td>
</tr>
<tr>
<td>Chemistry</td>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>37%</td>
<td>31%</td>
</tr>
</tbody>
</table>

Conclusions

Based on two years of results, there is solid indication that utilizing approaches like those described in the authors’ Mathematics with Real World Correlation project can make a positive difference with potential female engineers. Benefits include the following:

1. Improved comprehension of basic math and science concepts through connection to real world applications from students’ everyday lives
2. Early introduction of simple engineering concepts with inquiry based participation that makes engineering seem more interesting.
3. Exposure of female students to engineering applications that connect with societal issues that they can become passionate about.
4. Increased self-confidence in their ability to succeed in engineering careers.
These are all things that are fundamentally important if we are to interest more young women in engineering careers and improve our profession through increased diversity and broadened perspective.

References


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