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# Engaging Secondary School Students in Pre-Engineering Studies to Improve Skills and Develop Interest in Engineering Careers*

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*Academic institutions are finding that creating and maintaining a student's interest in engineering and technology during the secondary school years is critically important. The authors have combined experiences from their previous engineering careers with techniques from their current teaching positions to develop and pilot some new approaches to accomplish this. They were given a unique 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 were roughly evenly divided between male and female. These students represent a demographic cross-section that is in short supply in engineering today. They were selected for the program based on assessed potential for success in science, engineering, and technology programs. However, the students showed a significant lack of self-confidence in their abilities to succeed in such careers. Additionally, pre-course testing indicated a shortfall in basic math and science skills necessary for success in engineering. The month long program took the approach of connecting real world applications of simple engineering concepts to the basic skills necessary to analyze those concepts. After three summers of activity, the authors have had the opportunity to construct and deliver several different curriculum modules to multiple groups of students.*

**Keywords:** Outreach, K-12 education, pre-engineering.

## INTRODUCTION

IN THE PAST DECADE, the number of American high school graduates entering engineering and technology careers in college has dropped 35 percent [1]. The Commission on Professionals in Science and Technology has warned that if American universities cannot supply the required number and quality of engineering and technology (E&T) graduates, then employers will be forced to increase the trend of outsourcing their engineering needs outside the country [2]. One of the major ways that colleges can reverse this trend is by outreach to minority students and females, encouraging them to pursue E&T careers. Currently only about 10 percent [3] of students enrolled in E&T curriculums are minorities. According to T.K. Grose in the American Society for Engineering Education (ASEE) *Prism* magazine, "America's engineering and technology schools struggle to recruit and graduate minority students." [4] He goes on to say that low income minority students can present a special set of challenges, including how well they learn math and science in secondary schools. As to these challenges, Julia Clark states "Minority students, those who form the most rapidly growing portion of our school-age population, are the ones that are most left out of science and mathematics." She continues, "Curricular and instructional methodologies need to be updated to include cooperative learning and accommodate alternative learning styles. The program should be designed to foster enthusiasm, interest, and competence both for pursuing careers in the field, and for the acquisition of skills and knowledge demanded by an increasingly technological society." [5]

Regarding the shortage of women studying engineering, Sean Cavannaugh 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." [6] As regards women, there are varying theories put forward for their not pursuing engineering and technology plans of study. One is that they are put-off by engineering, which is stereotypically seen as a "guy" career [7]. Another is that young women may lack confidence in their math and science abilities. Regardless of which is the cause, Katherine Cromer writes, "Researchers say that if girls lose interest in math and science in middle school, when social pressures and gender

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differences become more pronounced, they typically won't find their way back to the subjects." [8] A study of women in university engineering programs shows that this shortage of self-confidence is a major issue [9]. 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." [10] Statistics show that minorities [11] and females [12] continue to be hugely underrepresented in most types of engineering. Universities are creating outreach programs in conjunction with public school systems, attacking the issue by creating pre-engineering programs in middle school and high school [13].

Collegiate engineering and technology programs are struggling to attract students. As Akram, Darwish and Green summarize, "Enrollments in engineering programs have not been keeping pace with expected job growth in industry. Administrators have been trying hard to increase enrollments, improve the retention rate for entering freshmen, and improve the percentage of engineering students completing an engineering program." [14] Felder and Brent agree, stating, "Declining interest in engineering among high school students in recent years has led to steep enrollment decreases in many engineering programs." [15] We have to ask ourselves, "why are less students entering engineering and technology studies, and especially, why are minorities and females so underrepresented in such programs, comprising less than 20 percent of the total students? [16, 17] Outreach programs to secondary schools are being tried in many places in the belief that they will eventually lead to increases in engineering enrollment [18, 19, 20].

A pre-engineering program designed to attract and assist secondary school students must recognize that logical thought processes and problem solving are major components of the skill set needed by an engineer, yet they are areas where a great many urban students have underdeveloped skills [21]. Replacing rote learning with participatory investigations, the authors have shown that mathematics, science, and problem solving skills can all be advanced by directly connecting classroom activities to topics that interest the students, and drawing them into participatory involvement. Strong asserts that such instruction facilitates students thinking beyond paper and pencil to how what they learn is evident and applied in everyday life." [22] Additionally, several studies have indicated a strong correlation between attitudes and achievement, especially with regards to math-driven topics [23]. This is important as pointed out by Ma and Kishor who showed that confidence correlates very positively with achievement [24]. Research by numerous authors has shown that self-confidence is imperative to success in any form of life, but most certainly in engineering programs [25, 26]. There is no better confidence booster than to do well at something. Thus the most effective program is going to be one that introduces new skills while directly relating them to things the student already understands, thus simultaneously advancing both confidence and skills.

During a three-year period, Professor Pete Hylton of the Mechanical Engineering Technology Department of Indiana University Purdue University Indianapolis (IUPUI) and Wendy Otoupal, a middle school mathematics teacher and an adjunct instructor for IUPUI were given the opportunity to participate in an outreach program in the form of a summer course for minority pre-engineering students. The groups were split about 50–50 on gender, and were comprised almost entirely of minority secondary school students from low socio-economic status households. Thus the groups were demographically ideal for addressing the areas where engineering admissions see the greatest shortfall. The objectives of the outreach program were twofold. First, by creating or enlarging an interest in engineering and technology careers, the likelihood of students entering these programs when they begin college should be increased. Second, the authors' experiences have shown that introduction of simple engineering concepts to secondary school students improves both their math and pre-engineering skills, as well as their self-confidence, by connecting the concepts to real world situations that they can relate to.

## THE CURRICULUM

Everyday Engineering—This module focused on exposing students to simple mechanical systems involving mechanical advantage, friction, force vectors, and structural characteristics. The concepts were ones that students encounter in everyday life. Students use mechanical advantage all the time, but they do not recognize it by that name. Mechanical advantage is achieved whenever we use a mechanical system to amplify our applied effort to give it greater effect. To demonstrate this on the first day, the largest boy in the class was asked if he could move a particular, heavy desk. After it was shown that he could not, a simple mechanical jack was given to the smallest girl in the class, who lifted the desk with ease, as shown in Figure 1.

The point was clear; mechanical advantage can make the girls as strong as the boys. This concept appeals greatly to young women at an age where they do not wish to appear unable to do things that their male counterparts can. This was followed by more mechanical advantage concepts, using common devices such as pulleys, or common hand tools such as pliers, vice-grips, etc. The mathematics needed to determine the advantage gained is not difficult. If the systems are kept simple, it is possible to use simple ratios and

Fig. 1. A student demonstrates the mechanical advantage provided by a mechanical jack before learning how simple math and engineering concepts can be used to analyze such a system.

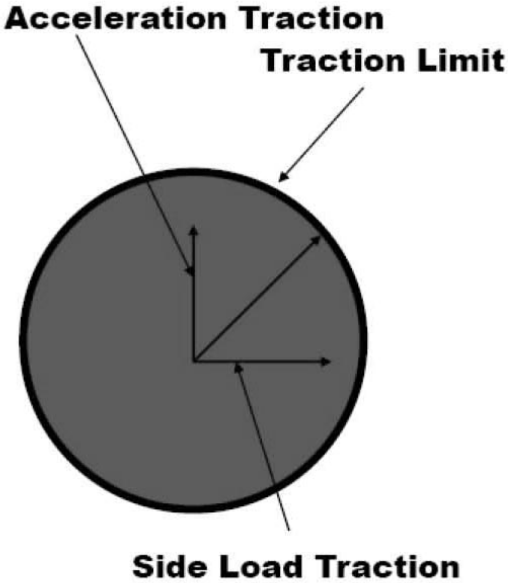


Fig. 2. A friction circle, used in the motorsports industry to determine whether a car has exceeded its cornering capability, is an excellent example to teach students how to use vectors.

basic algebra to analyze simple systems. These are math skills that high school students should know, although they are often underdeveloped. Friction and vectors do not hold a lot of interest outside the classroom for many of these students. However, with their eyes set on a first driver's license, how a cars stays on the road in a corner, is something that does, in fact, interest them. Thus, the concept of a friction circle, as shown in Fig. 2, is a great way of bringing vectors into their sphere of thinking. It can be used to determine how fast a car is capable of going around a corner, rather than exceeding the car's traction limit and ending up in the ditch [27].

Environmental Footprint—A number of studies have suggested that women tend to seek careers where they can make a difference in society and apply less traditional solutions. Too often, engineering is not seen as one of those careers. For these

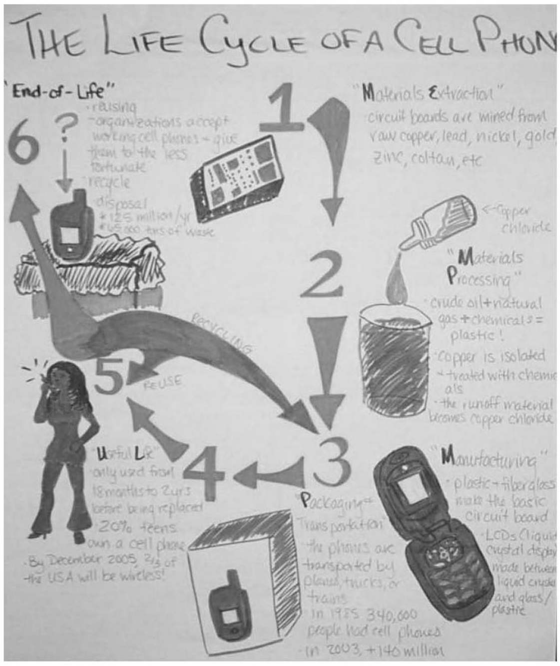


Fig. 3. This student poster demonstrates how the environmental curriculum module helped students understand the impact of a simple device on their environment.

reasons, one of the modules constructed focused on sustainable engineering and environmental impact, thus tying readily to current societal concerns. The students conducted a study of the environmental footprint created by one of their favorite devices; the cell phone. They learned the process by which cell phone circuit boards are made, and the toxic waste byproducts that come from that process. They conducted chemical experiments on dilution, metal extraction from waste water and evaporative processes. They even built and tested their own miniature version of a landfill, examining leaching of chemicals into groundwater aquifers. These topics were always tied closely to the necessary mathematics, whether in calculating dilution concentrations, balancing chemical equations, or extrapolating laboratory-sized experiments to the size necessary for an entire city. The student poster shown in Figure 3 demonstrates how one particular student came to understand the life-cycle of a cell phone.

After the environmental footprint study, students were placed in a scenario as if they lived in a small town which had the opportunity to become the home of a new chemical plant which would be involved in the chemical processes they had just studied. Students had to weight the consequences of this new company on the town, considering the effect on unemployment and dwindling tax base versus the environmental impacts that they had just examined. They split into two sides, pro and con relative to the coming of the new company, and had to research and prepare an argument supporting their side in a simulated town council meeting. The young

Fig. 4. The module on designing safety structures allowed students to apply their lessons to construction of a vehicle that would protect a passenger (in this case an egg) in a high speed crash.

women on both sides 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. 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 [28].

Safety Through Motorsports—This curriculum module discusses the design of motorsports vehicle safety structures in broad terms applicable to secondary school students. Included are topics from physics such as kinetic energy, energy absorption, and material strength. Concepts from math are involved, showing how the principles from physics can be used to calculate applied forces and loads on a moving structure. Students design and construct crash-test vehicles with the objective of protecting an egg in a crash scenario, as shown in Fig. 4. The module uses the high energy and exciting aspect of motorsports to catch and hold the attention of the young people involved. But it also connects to the need for societal benefit by showing how these designs are eventually integrated into passenger car technology, protecting all of us on the street. This module was the third one developed and has had the least field testing. Although it is still under development, initial experiences indicate that it has an even greater potential than the first two modules to demonstrate to students the appeal of engineering careers [29].

## RESULTS

The first year that the summer program was conducted, the twenty-one participating students were given an assessment test on the first day and again on the last day. The questions were designed to assess their understanding of basic engineering and math concepts. The expectation was that after a month of being exposed to the pre-engineering curriculum, that students would show a significant gain in their engineering skills and hopefully some associated gain with their math skills. The results were segregated by gender. The young men began the course with a mean score on engineering questions of 23.33 and a margin of error (ME) of 9.46 for a probability of 99.975% ($p < 0.025$) and finished with a mean score of 68.33 with an ME of 2.74 ($p < 0.025$). Similarly the young women went from a mean of 15.38 (ME = 1.88, $p < 0.025$) to a mean of 58.90 (ME = 1.88, $p < 0.025$). Thus, on engineering topics, both genders showed a statistically significant gain in their understanding of the engineering concepts, with the males slightly ahead both before and after.

The surprise coming out of year number one was the large increase in math scores. The young men began with a mean score of 60.00 (ME = 13.35, $p < 0.025$) and improved to a mean score of 90.00 (ME = 3.33, $p < 0.025$) while the young women went from a mean of 55.90 (ME = 4.96, $p < 0.025$) to 81.53 (ME = 7.02, $p < 0.025$). While some improvement had been expected, this data indicated that focusing on the engineering aspects of the course significantly improved their math skills, presumably because seeing the math techniques used on real world activities either helped the students grasp the math better, or gave them an increased incentive to understand the math.

For year number two, there were twenty students assigned to the class. There were a couple of changes relative to the conduct of the course. Some of the students from year one had opted to sign up for a second year of the activity. Interestingly, all of the repeating students were young women. This led the instructors to speculate that the first year course had offered a significant boost to their self-confidence, and they came back for more. Literature on students entering engineering indicates that self-confidence is a huge factor for females. Toward this end, the instructors decided to add an assessment of attitudes and self-confidence to the program. Additionally, a new curriculum module had to be added due to the presence of the repeats, and it was aimed at females by basing it on environmental engineering which has been shown to address female needs for societal relevance.

Let us consider the results of the male students in year two, who for the most part, were exposed to exactly the same curriculum as year one. The young men improved from a mean score of 24.29 (ME = 7.50, $p < 0.025$) to 53.33 (ME = 7.38, $p < 0.025$) in engineering topics and for math topics they improved from a mean score of 67.14 (ME = 5.93, $p < 0.025$) to 73.81 (ME = 6.65, p , 0.025). Clearly the males showed positive gains similar to year number one. New assessment questions were created to address the young women exposed to the environmental engineering module, and they showed a mean pre-course score of 26.7 (ME = 6.40, $p < 0.025$) in engineering with a post-course score of 46.76 (ME = 11.08, $p < 0.025$). In math, the mean score changed only from 80.00 to 85.00, lacking statistical significance. This indicated that the new module had the desired effect of producing an increase in engineering understanding, but that, with a high in-coming math score, due to the repeats from year one, it was more difficult to see a significant increase. This will be seen again in year three and discussed more at that time.

An attitude and self-confidence assessment was added for year two. It consisted of a series of Likert scale questions asking students how strongly they agreed with certain statements. The scores from the males and females were virtually indistinguishable, so the two genders have been treated together. The scores from two of the statements showed a statistically significant change, and a noteworthy inference. "I believe that I can get a good job without being good at math" saw an increase from a mean score of 1.88 (ME = 0.44, $p < 0.025$) to a score of 2.59 (ME = 0.73, $p < 0.025$). "I believe that I can get a good job without being good at science" received scores that increased from 2.58 (ME = 0.45, $p < 0.025$) to 3.18 (ME = 0.55, $p < 0.025$). At first glance, it might not be obvious what these scores indicate. However, having worked with the class, the authors believe that the students have, in fact, gained a belief that they can perform the math skills necessary to succeed, without being math geniuses. The general post-course skills of the students indicate that they realize math is necessary to perform engineering tasks, so the responses to the survey appear to mean that they now see their way clear to achieve science and engineering goals using math skills they feel capable of mastering, rather than skills that they feel are above them. This could be key in continued student progress in mathematics. As Ma and Wilkins concluded, "A person's mathematical disposition related to his or her beliefs about and attitude toward mathematics, is as important as content knowledge for making informed decisions in terms of willingness to use this knowledge in everyday life." [30]

The authors' interpretation is reinforced by the response to yet another survey statement, "I believe I could be a good engineer" which showed an increase from a mean of 1.76 (ME = 0.42, $p < 0.025$) to 2.65 (ME = 0.63, $p < 0.025$). These results went even higher with the group of repeating females, who showed an average post-course score on this statement of 3.50 (ME = 1.59, $p < 0.025$). Similar results have been seen by other examiners performing pre-engineering outreach activities to pre-college students. [31, 32, 33] A number of investigators believe that this is due to the fact that students are not presented, in their elementary and secondary school classrooms, a correct view of what engineering is about. [34, 35] As Klenk, Barcus, and Ybarra stated, "Unfortunately, science related careers are generally perceived by children as unglamorous, math-intensive, and something for 'geeks.' The U.S. is facing a critical shortage of engineers, and students are not receiving adequate information about careers in engineering in either their homes or their schools." [36]

Interestingly, the cohort of students assigned to the program in the third year were appreciably different. First, there were only twelve of them. Second, they were almost all from the sponsoring school system's new math/science magnet school. Consequently, these students were expected to be much better prepared in terms of their math and science skills. Third, as one would expect, their understanding of engineering and their self-confidence were also higher. Fourth, the age (i.e. grade level) spread was greater (ranging from incoming–freshman to incoming–senior), which led, not unsurprisingly, to a much larger standard deviation on the skills scores. Given all of these new variables, and the much smaller sample size, it was not possible to perform the same statistical treatment on the third year cohort with any meaningful level of confidence.

However, speaking qualitatively, the students in year number three showed a much smaller change in skills scores, and less growth, start-to-finish, on their Likert statements. Rather than being viewed as disputing the previous results, this cohort's performance actually supports the main results. First, by having come from the math/science magnet school, these students had already seen a more intensive math and science curriculum, and therefore there was less room for their scores to change. So it is no surprise that there was not as impressive an improvement between start and finish of the summer course. Second, having been exposed to more engineering concepts in their school, they already had fairly high self-confidence relative to their ability to succeed in engineering, and they had a much better understanding of what engineering could be. This is exactly what the literature and the results from the first two years indicate should happen. Also, the summer instructors had not been informed of the change in the makeup of the third year cohort, so no curriculum modifications had been made. Therefore, the material presented was not enhanced to account for the fact that these students were already better prepared or presented a broader skill level. Thus it was not as beneficial to them as it would have been had the modules been prepared specifically for this cohort. This reinforces the need to take these factors into account in preparation for an enrichment program such as this was intended to be.

## CONCLUSIONS

Results of student participation in the challenges and opportunities presented thought the described activities, have led the authors to conclude that, if student paradigms are connected to science and math through authentic exposure, the learning becomes meaningful in ways that it would not otherwise. One result is that student feelings towards engineering improve noticeably. This paper has presented a variety of ways that the authors have worked to achieve improved engagement, using examples from engineering in an urban secondary school, summer enrichment setting. Specific conclusions include the following:

1. Results showed improved comprehension of basic math and science concepts through connection to real world engineering applications from students' everyday lives.
2. The early introduction of simple engineering concepts with inquiry-based student participation makes engineering seem more interesting to the participants and improves self-confidence.
3. There is a strong correlation between student self-confidence and ability to learn math and science skills.
4. As the student gains confidence, he or she feels more capable of attempting bigger problems. And as solutions are found to larger problems, confidence in the ability to learn even more complex topics continues to increase.
5. Any logical means of starting the process of boosting skills and confidence at the same time will stand to give pre-engineering secondary school students a boost when they begin their collegiate careers and make it more likely that they will consider careers in engineering.
6. Exposure of female students to engineering applications that connect with societal issues improves their interest in potential engineering careers.

However, there are pitfalls to be avoided. The curricular materials and the skill level of the students should be matched so that the students are neither too advanced for, nor bored by, the material presented. The age level of students should not be too broad, as a disparity in skill level and maturity will diminish effectiveness. An outreach program should not be expected to fill the needs of both a remediation for some students and an enrichment experience for others. If that occurs, both will likely lose, or at least, feel short-changed.

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