Coupling Math and Engineering Concepts in a K-12 Classroom Environment

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Abstract

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 their engineering backgrounds with their current teaching careers, to develop and pilot some new approaches to accomplish this. Both authors had over twenty years of experience in the aerospace industry before choosing career changes into the academic world. One now serves as a professor at a university with a well respected Engineering and Technology program, the other teaches middle school Mathematics in a K-12 unit which is designated as a curriculum development site for a large, urban school system. Together, they have created an approach they call "Mathematics with Real World Correlation" in which they introduce simple engineering concepts in conjunction with mathematics topics. This has proven to yield improved mathematics scores while also increasing student interest in Engineering and Technology.

Why is Engineering Important in the K-12 Environment?

Engineering and Technology programs at a great many universities are struggling with attracting 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." [1] Felder and Brent express similar conclusions, stating, "Declining interest in engineering among high school students in recent years has led to steep enrollment decreases in many engineering programs."[2] Universities must ask themselves why less students are enrolling in Engineering and Technology programs, and furthermore, why minorities and females are grossly underrepresented in such programs, typically comprising less than 20% of the students.[3, 4]

As regards the high school females, there are commonly two theories as to why they are not pursuing Engineering and Technology careers. They may be either scared off by what is stereotypically seen as a "guy" subject, or they may lack confidence in their math and science abilities. Either way, Katherine Cromer writes, "Researchers say that if girls lose interest in math and science in middle school, when social pressures and gender differences become more pronounced, they typically won't find their way back to the subjects."[5] Sean Cavanagh adds that females "have less confidence in their math and science abilities, and take less enjoyment from those subjects, than their male peers."[6] He goes on to point out that their lack of confidence is not due to a lack of ability, they simply question their own chances of success.

As for minority students, Julia Clark points out "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 goes on to say, "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 filed, and for the acquisition of skills and knowledge demanded by an increasingly technological society." [7]

There is a need to address the declining overall enrollment in Engineering and Technology programs, as well as increasing the diversity of the E&T workforce. Attracting more minorities and females to E&T programs would have a positive effect on both these issues. One path of attack is to create better pre-college preparation in the K-12 world. Chubin, May and Babco point out that "Targeted strategies have been shown to have the potential to increase the number of underrepresented pre-college (K-12) students progressing to college STEM programs. An effective pre-college program must (1) promote awareness of the engineering profession, (2) provide academic enrichment, (3) have trained and competent instructors, and (4) be supported by the educational system of the student participants." [8]

The authors are actively engaged in developing creative classroom modules for use in secondary school systems which introduce simple engineering concepts to pre-college students. The modules have been tested with students, predominantly minority and female, from a large urban school system. Objectives are twofold. First, creating or enlarging an interest in Engineering and Technology careers while the students are still in middle school or high school will hopefully increase the likelihood of students entering these programs when they begin college. Secondly, the authors experiences have shown that introduction of these simple engineering concepts to secondary school students improves their math comprehension and their self confidence by connecting the concepts to real world situations that they can relate to.[9]

Developing a Curriculum to Address the K-12 Student

The attempt to develop an improved classroom module for secondary school students began with the recognition of an age old excuse for not learning math and science. The excuse was heard in classrooms when the authors were students, and is still being heard today in the classrooms where they teach: "I'll never really use this." The authors decided to defuse this argument, and show the students that they actually do encounter, and use, science and math concepts in their everyday lives. For example, mechanical advantage, or leverage, is a concept that the students encounter all the time, without even realizing it. A mechanical jack, using no hydraulics, and nothing but simple leverage, makes an excellent demonstration, because it allows the smallest of students in the classroom to lift a heavy lab desk. How can the smallest member of the class lift what the largest and strongest members would have been unable to budge, unaided? The answer is mechanical advantage. Mechanical advantage is explained as a way of amplifying your own strength, a description which could be clearly seen with the jack demonstration. The floor jack in question is not a particularly simple mechanism, so after the initial introduction, it was put aside and less complex tools were analyzed. Pliers, wire cutters, limb cutters, claw hammers, levers, and pry bars were all examined as simple means of increasing an applied force using mechanical advantage. Every one of these was a mechanism that the students had seen, and in most cases, used. However, they had not actually understood the principles that they were applying.

In an effort to engage the students, they were urged to figure out which tools gave the most mechanical advantage. They also were asked to figure out how to improve, or optimized the amplification of the applied forces in each mechanism. In order to do this, it was necessary to utilize math concepts that they had previously not shown much interest in. However, now they saw a direct connection between the math and something real in their lives. Before long, some of the students were willing and able to move beyond simple pliers, and start analyzing channel lock pliers, or vice grips. In the end, a pair of students even decided to take on the more complicated floor jack and try to analyze and quantify the amount of mechanical advantage gained through the mechanism. They did a credible job, despite the complexity of the device.

What other forms of mechanical advantage have the students seen? Several recent popular motion pictures have dealt with sailing ships of one fashion or another. The students were asked to ponder how much the canvas sails on older ships must weigh. How in the world were one or two sailors able to hoist sails weighing that much all the way to the top of the masts? That is when the instructor pulled out a block and tackle system and a length of rope. Starting with a discussion of how the tension in a rope had to be the same anywhere along its length, no matter how long the rope was, the students were soon designing looped systems with pulleys that amplified their pulling power via mechanical advantage. Problems were designed that forced the students to analyze various systems and use algebraic solution to determine the advantage gained. Before long, students were picking out mechanical advantage systems all around them, and asking for help in analyzing them. By connecting to simple engineering concepts, their ability to apply mathematical concepts improved noticeably.

In a similar vein, the concept of a car tire's friction circle was introduced. This concept is used in the auto racing world to represent the fact that a tire only has so much adhesion capability. That capability can be used up in acceleration/deceleration or in side load/cornering ability. If the total capability of the tire is exceeded, then either wheel spin or sideways slide will result. Since for many middle school and high school students, their perceived future revolves around their ability to drive a car, this is an area of considerable interest to them. After all, what teenager is not interested in figuring out whether their car will make it around the corner at a given speed rather than ending up in the ditch? However, having been presented the friction circle concept, it becomes obvious that the solution to the problem involves vector math, another concept that is often viewed as "not needed" in the supposed real world. Suddenly, the ability to analyze and combine vectors has renewed emphasis to these students.

Conclusions

Lynda Wiest, in writing for Mathematics Teacher magazine, says "Educators have an important opportunity and responsibility to help all students within their charge, succeed in their content area. To achieve equity this means expending extra effort on behalf of those students that have been marginalized or are under represented in a field." Such students "need to see that mathematics is relevant to their lives and that it is something that they can do."[10] The authors of this paper agree wholeheartedly, and also believe when student paradigms are connected to science and math concepts through authentic exposure, the learning becomes meaningful in a way that it otherwise would not.

The previously referenced results[9] show that the authors have achieved some success in connecting real world situations to mathematical concepts in a way that pre-college students, particularly minorities and females, seem able to relate to. A plan of study was developed which coupled simple engineering concepts with the math skills needed to understand and analyze them. This plan of study has been presented to classes which are predominantly minority and female. Given that the state standards do not incorporate such technical concepts in secondary school, it is not surprising that a comparison of pre- and post- class assessment tests indicated a large increase (46%) in understanding of the engineering concepts. Of potentially greater interest, however, was the significant improvement (21%) in the comprehension of the math concepts, which was also demonstrated. A more qualitative benefit of the class was that several students experienced a noticeable improvement in their self-confidence with regards to possible engineering careers. All of the students involved were either minority or female, two groups that are significantly under-represented in most Engineering and Technology programs. That makes these results even more valuable, as universities scramble to develop strategies to bring these students into their programs. This paper has briefly described the ongoing development of classroom modules aimed at furthering this concept, which the authors have named "Mathematics with Real World Correlation." The conference presentation will incorporate more details of the techniques used and will also indicate additional results from the use of these modules with high school students during the summer of 2005.

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Biographies

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