Integration of Engineering Principles in High School Algebra Courses

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Abstract

In 2003 the state of Maryland implemented an education initiative which requires all Maryland students to enroll in algebra classes and pass a high school assessment in algebra/data analysis in order to graduate. Our *Introducing Engineering Through Mathematics* project, funded by the National Science Foundation (EEC - 212101), introduces entry level algebra students to simple yet valuable engineering problems and applications which can be solved using algebra.

The development of the curriculum is a collaboration among UMBC faculty and students, local middle-school and high-school teachers, UMBC's Center for Women and Information Technology and the Maryland State Department of Education. Many students fail to recognize the importance of algebra in their lives when only exposed to simple applications of algebra (two trains traveling in opposite directions, the eastbound train travels at 80 mph and the westbound travels at 60 mph; determine when the trains will be 490 miles apart). They are often unaware that these same simple algebra skills can be used to solve very real and important engineering problems (e.g. determine the speed at which an aircraft must fly in order to stay aloft). Through increased awareness and relevance an early interest in pursuing engineering as a career may be achieved.

The curricula developed in this project targets simple engineering problems in fluid mechanics, electricity, and structures that can be solved using algebra. The curricula are provided on CD's with videos of hands-on activities and explanations. A week-long training workshop will be conducted summer 2004 for in-service mathematics teachers and undergraduate teaching fellows. The undergraduate teaching fellows[1] will provide hands-on instructional classroom support for the middle-school and high-school teachers, helping them to integrate the CD curricula into their courses.

Introduction and Rationale

"Today's U.S. economy depends more than ever on the talents and knowledge of skilled, high-tech workers"[2]. While the National Science Foundation predicts employment for engineering occupations to increase by an average of 20% between 1998 and 2008[3], overall enrollments in engineering have decreased since 1992[4]. As a result, the U.S. Bureau of Labor Statistics predicts a national shortage in the engineering workforce with the next decade[5]. Although an increasingly large proportion of the U.S. workforce consists of women and underrepresented minorities, current data indicate that women comprise only 9 % and minorities of 4 % of the engineering workforce[3, 4]. Based on such data, engineering has been described as a "demographic collision course with the future"[6]. To meet the national need, it is imperative to attract higher numbers of students, particularly women and underrepresented minorities, to engineering and technology-based careers.

A significant percentage of important events in the 20th century were directly related to technology [7, 8] and a growing number of decisions faced in our society involve technical issues[9]. Yet as a society, we know very little about technology and engineering[7]. In an NSF survey conducted over the past 2 decades, 90 % of U.S. adults report being very interested or moderately interested in new scientific discoveries and the use of new technologies. However, only 17 % of those surveyed felt well informed or moderately well informed about science and technology, and thirty percent felt poorly informed[2].

Technological illiteracy among the general population may be linked to the lack of diversity in the engineering profession. According to Sheila Widnall, Vice President of the National Academy of Engineering, there are two primary reasons why women don't go into engineering:

1. Lack of understanding of the connection between engineering and the problems of our society. Lack of understanding about what engineers do.
2. Lack of visible role models and other women students in engineering[10].

A lack of understanding of what engineers do is common in the general U.S. population. William A. Wulf, President of the National Academy of Engineering, describes engineering as follows:

> *"Science is analytic – it strives to understand nature, what is. Engineering is synthetic – it strives to create what can be. **Engineering is creating, designing what can be**, but it is constrained by nature, by cost, by concerns of safety, reliability, environmental impact, manufacturability, maintainability, and many other such 'ilities'".*[11]

Yet, results of a poll commissioned by the American Association of Engineering Societies showed that only 2 % of the public associate the word "invents" with engineering, and only 3 % associate the work "creative" with engineering[12]. Promoting a better understanding of engineering at the grass roots level will not only lead to higher levels of technological literacy, but may also work to increase diversity in the engineering profession.

An increase in diversity in engineering is imperative, given the workforce predictions cited in the Introduction. Since 1992, overall enrollment in engineering dropped 3 % and dropped 9 % for minorities in general and 17 % for African Americans[12]. This decline in numbers and percentages of minorities in engineering was a specific concern raised by the 2000 NSF report on Women, Minorities, and Persons with Disabilities in Science and Engineering[3].

This project will increase the interest of women and other underrepresented groups in engineering and technology by using hands-on activities that promote active participation by all groups. To promote access and participation of teachers and students from historically underrepresented groups, teachers will be targeted that serve large numbers of students representing low-income families (Census data indicates that the connection between low-income and minority households is still strong.). In Teaching the Majority: Breaking the Gender Barrier in Science, Mathematics, and Engineering[13], Sue Rosser identifies the major barriers to learning that most often affect girls, but also have an impact upon other underrepresented groups. The following factors as described below will be addressed:

1. *Ignoring students' motivation in the classroom* – Many students look at mathematics education as a requirement without much usefulness in their lives, now or in the future. Providing interesting, fun applications of engineering with ties to real-world applications will help motivate students. Providing career information will help students understand the opportunities for employment that exist in engineering and technology sectors.
2. *Unequal background preparation* – Capable students from nontraditional backgrounds may become discouraged because of weak prior preparation for engineering and technology education. Providing CD's with videos of the hands-on activities and explanations will allow all students to successfully move through the curricula process at their own pace.
3. *Lack of social usefulness* – Multiple research projects have shown that girls and women prefer to use engineering in an application of social usefulness. Providing hands-on activities that are "problem-solving" connection to other disciplines and are focused on the current and future needs of society will provide a context for learning.
4. *Teaching methods and style* – Traditional college level engineering courses typically involve passive learning with theory taking precedence over application. Research has shown that girls learn better with frequent interactions and positive reinforcement. Minorities often learn better in small group settings. The use of hands-on activities has been shown to raise science achievement scores[14] and improve girls' achievement[15]. The activities are fun and work to show all students that they are capable of succeeding in engineering or technology.
5. *Lack of role models* – Programs for pre-college girls that combine hands-on activities with the provision of role models have been shown to lead to increased interest in math, engineering, science, and technology courses and careers[16-18]. Taryn Bayles and Anne Spence, two female engineering faculty members, are leading the development of curriculum and program activities.

Project Objectives:

Goal: To develop a model program which incorporates simple engineering applications in the algebra curriculum in order to increase the awareness of engineering as a career and increase the number of students enrolling in engineering programs.

Objectives relating to the goal: The program incorporates five objectives in order to attain this goal:

- Develop CD curriculum kits that target different fields of engineering (chemical & mechanical, electrical, and civil) that can be used in both middle and high school algebra classes;
- Provide a summer workshop for in-service mathematics teachers and undergraduate engineering Teaching Fellows;
- Develop an undergraduate engineering Teaching Fellows program to provide hands-on instructional classroom support for middle and high school algebra teachers to help them integrate the CD curricula into their courses;
- Maintain student interest in engineering at schools through the development and institutionalization of an after-school engineering program that culminates in a series of collaborative and competitive activities;
- Increase the involvement of females and other underrepresented groups in engineering by providing female and minority engineering role models in the classroom and developing curricula that encourage interest and participation by all groups.

The details of the *Introducing Engineering Through Mathematics*[19] project were presented last year at the ASEE annual conference. This paper presents the preliminary hands-on activities of the fluid mechanics curriculum CD.

The Fluid Mechanics Curriculum

A team of college faculty and middle/high school teachers have been working together to develop the CD curriculum kits that are easily usable by algebra teachers. CD kits were selected because they are easily transportable, easy to disseminate, and support the use of technology. The curriculum is interwoven with the Maryland State Department of Education Content Standards. The curriculum will be reviewed by in-service algebra and geometry teachers that are in a teacher training program to upgrade their skills at Loyola College in Maryland.

The hands-on activities listed below are some of the demonstrations that have been included on the Fluid Mechanics CD. Many of these activities have been developed by others and were selected to tie in with the fluid mechanics algebra curriculum. In addition, some of these activities have already been used for a High School outreach project[20] which is part of our STEP (Science, Technology, Engineering & Mathematics Talent Expansion Program – NSF DUE – 0230148) project[21]. One component of the project is to create an interest in STEM (Science, Technology, Engineering & Mathematics) fields among high school students when 90 upper level UMBC mechanical and chemical engineering students, divided into teams, visit ten high schools per year to introduce high school students to physics, chemistry, biology, mathematics or technology concepts using hands-on activities.

Air Pressure:

- Every kid knows how to make a straw work, but why does it work? For this experiment have the following set ups:
  1. A straw resting in a paper cup of colored juice or punch.
  2. A straw with a couple of pin holes punched in halfway up the straw resting in a paper cup of colored juice or punch.
  3. A straw inserted through a cork or one-holed rubber stopper into a 125mL Erlenmeyer flask containing colored juice or punch.
  4. Two straws and a cup of colored juice or punch with a card having instructions to put both straws into your mouth, to place only one of the straws into the liquid and to suck simultaneously on both straws.

  Ask the students to relate what happened or didn't happen in each instance and explain the observations. Then ask them to explain "what did they do with their mouth and jaw as they sucked?"

- Fill a jar to the top with water and wet the rim slightly. Lay an index card on the top of the jar. Hold the card firmly in place and turn the jar over. Now take away your hand and see what happens. *(The water should stay in the glass, showing that air pressure is exerted on the card from the top, side, and the bottom.)*

- Lay an ordinary wooden ruler on the table so that about 1/3 of it lies over the edge. Place two sheets of notebook paper on the ruler and press against the table until the paper is flat as possible. Now hit the overhanging portion of the ruler with your hand and try to make the paper fly into the air. Repeat this procedure using two sheets of unfolded newspaper and record the results. *(The ruler should snap when placed under the newspaper, but not when placed under the notebook paper. The notebook paper is small enough that the ruler can lift it without breaking, while the newspaper has a much greater surface area than the notebook paper. The air presses down on the sheet of newspaper, there is a lot of air pushing down on it and this is enough to stop the paper and ruler from moving.)*

- Obtain a large mouth jar (a large institutional sized pickle jar from the cafeteria works well). Get a large plastic sandwich bag and invert over the mouth of the jar. Push it into the jar and smooth it out so that it clings to the inside surface. Securely tape the bag to the mouth of the jar. Challenge the student to reach into the jar and pull the bag out. They will not be able to do this unless they rip the bag. Why? Point out that there is no glue or other type of adhesive holding the bag to the jar. *(It is clear why the sandwich bag can not be pulled out of the jar, if the bottom of the jar is 25 cm in diameter, and then the area is πr^2 or $3.14 \times (12.5\ cm)^2 = 491\ cm^2$. Now the weight of the air pushing down on the bottom of the jar is $491 \times 1030 = 50560$ g, or 50.56 kg or 111.4 lb_f of air.)*

- Have two students come up and get two rubber plungers, and push them against each other. Ask them to now pull them apart. They will come apart very easily. Have the students reattach the plungers, and hold them together making sure that the hole is covered with your thumb. (It works even better if your thumb is wet.) Now when students pull on the plungers they will stick together. *(Because there was a hole in one of them, air was allowed to come into the gap, meaning that the pressure on the inside and outside was the same. The pushing together of the plungers forced out the air and by plugging the hole, air was prevented from coming in and equalizing. , Now when the plungers are pulled apart the volume of the air trapped inside increases, lowering the pressure. Because all of the outside air pressure pushing on the outside of the plungers is many times greater than the small pressure on the inside, the plungers are not easily separated. The total force can be calculated from the total surface area of the two circles multiplied by 1030 g. If the plungers have a 10 cm diameter there is about 150000g, or 150kg, or 330 lb_f of pressure holding them together.)*

- Heat two 'empty' Coke cans heating on a hot plate. Use tongs to pick up the can and rapidly turn it upside down and throw it into a pan of ice water. Instantly it will be crushed. Repeat using a Diet Coke can. This time there will only be a slight implosion of the can. *(The trick: In the classic Coke can, add a few mL of water, so that the heating fills the can with gaseous water. In the Diet Coke can, only hot air fills the can. Upon rapid cooling the gaseous water changed to liquid water (the volume changed by a factor of 70) reducing the pressure inside the can drastically. The air pressure pushing in on the can and down on the water in the can immediately crushed the can and forced water inside. In the Diet Coke can the cold water merely cooled the hot air down with very little decease in volume.)*

- Ask students to predict the tallest straw that they could build that would allow them to drink a soda. Indicate that they can join two, three, or more straws together to make a "super straw." (A short slit in one straw will allow the joining. A tight strip of tape to prevent leakage is recommended.) Have teams work on this problem. *(The maximum height that they will be able to draw the liquid up is about 33 feet. This is equivalent to a pressure of 760 mm of mercury. In other words, the outside air pressure can only push up water to a height of about 33 feet, no matter how hard they suck. Because Coke has all the sugar in it and its density is greater than pure water, they may not even be able to get it to rise 33 feet.)*

Buoyancy

You will need:

- Tall glass or graduated cylinder
- Large bolt or screw
- Piece of thread about 30 centimeters (12 inches) long
- Water and at least one other liquid. Corn syrup is a good choice.
- Spring scale.

Here's what to do:

1. Tie one end of the thread around the screw. Make a loop at the other end to hang on the hook of the spring scale.

2. Weigh the screw and record your result. *(Have the students complete Table 1)*
3. Submerge the screw in water and weigh it again, making sure it is fully submerged but not resting on the bottom of the container or against the sides.

Table 1: Buoyancy Experiment Measurements

Name of Object: Volume of Object (cubic centimeters): Density of Object (grams / cubic centimeter):		
Fluid	Density of fluid (grams / cubic centimeter)	Weight of object (grams)
air		
water		
corn syrup		

Bernoulli Principle

- Suspend two plastic balls, about 3 cm apart from a horizontal support. Ask the students what they expect will happen if they blow in between the plastic balls. Do this experiment and observe the results. *(The students usually expect the plastic balls to separate further, but the opposite is the result; the plastic balls move together! Blowing between the plastic balls creates a stream of air that is moving faster than the surrounding air. The pressure between the plastic balls is lower than the pressure of the air surrounding them, so they come together.)*

- Take a 3 x 5 index card and draw two lines each 1 inch in from the end. This will produce a 3 x 3 square and two 3 x 1 inch rectangles. Fold the two one inch flaps at right angles to the card. Place the card on the table so that it is resting on its folded edges. Predict what will happen when you blow air through a straw at the card (perpendicular to the top of the card). Do it and observe the results. *(The center of the card will bend downward and the card will not flip over.)*

- Light a candle and set it on the table. Predict what will happen if you blow through the funnel at the flame. Direct a funnel at the center of the candle flame and blow the candle out. Blow through the narrow end. What happened? *(The flame will not blow out, and will actually be drawn back toward the center of the funnel.)*

- Place a hard boiled egg in a tall narrow glass. Since hard boiled eggs normally sink when placed in water, ask the students how you can lift the egg to the surface without turning the glass upside down or reaching our hand or any other tool into the glass. All the students' need is water. *(Turn on the water and adjust the flow to be steady. If the flow is directly on top of the egg, the egg will rise to the water surface. Explanation: The fast moving fluid causes lower pressure. At the correct flow of the stream, there will be a pressure above the egg low enough so that the upward force of the overflowing water will cause the egg to rise to the surface. A sudden stop of the water flow will make the egg sink.)*

- Place a long-stem funnel next to a plastic ball. Say to the students, "I bet you can't pick up the ball with the funnel without sucking through it. You may not touch the ball with your hands or any other tools. The funnel must at all times remain above the table." *(Pick up the funnel and place it over the ball and* ***blow*** *through the stem while picking up the funnel. The ball will come with it. There is a region of lower pressure in the center of the funnel. Since this is over top the ball the pressure is lower here than underneath. If you have enough lung capacity you can point the funnel in all different directions and it won't come out of the funnel.)*

- The students are given a Ping-Pong ball, 2 small paper cups (2-3 inches tall), and some masking tape. Have them tape the cups onto the top of a table about three inches apart. Put the Ping-Pong ball in one of the cups, and challenge the students to get the Ping-Pong ball out of the first cup into the second cup – neither the cups nor the ball may be touched by any solid or liquid. *(Blowing across the top of the cup will produce lift on the ball and the ball will pop up out of the cup when the air speed is high enough. Controlling the ball's motion to get it to land in the second cup is not easy!)*

- The students are given a round piece of cereal, and a bendable drinking straw. Challenge the students to get the cereal to hover above the straw. *[Bend the straw to a right angle and put it in your mouth like a pipe. Take a deep breath, then, with the cereal held above the straw opening, gently and with control, blow air at the cereal. Let go of the cereal once you start blowing. This takes practice! The cereal will stay roughly at the same height because forces upward (the air stream) and downward (gravity) on the cereal are balanced.] This is more easily demonstrated using toy blow pipes or with a hair dryer and ping-pong ball (the angle of the hair dryer can be varied to further demonstrate the effect of velocity, air pressure and gravity.)*

- The CD also contains animated pictures that explain the different forces acting on an airplane in flight. The students then go through an algebraic animation of the solution of the Bernoulli equation to determine the upward lift that is required to keep an airplane aloft. Two demonstrations are also included to explain lift and airfoils.

Summary

The filming of the above hands-on activities took place summer 2003 and the curriculum development team has created a series of worksheets for the algebra students to use for practice to accompany the fluid mechanics CD. Loyola College in Maryland has an on-going mathematics teacher-training program designed to upgrade the skills of in-service teachers in the area of algebra and geometry. Currently, these classes of twenty teachers at Loyola College are reviewing the fluid mechanics CD to provide input from the teachers on all aspects of the materials prior to presenting the curriculum to other in-service teachers that will be attending the 2004 summer workshop. Filming of the electrical engineering CD is currently underway, as well as the development civil engineering curriculum.

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