Engineering Applications in the Early Algebra Classroom

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INTRODUCTION

A Maryland State educational initiative implemented in 2003 will require all Maryland students to pass an assessment in algebra/data analysis in order to graduate from high school. Concurrently, Maryland is concerned about its ability to attract students to the field of engineering. One solution to both concerns is to introduce students to hands on engineering applications in their algebra classrooms via CD curriculum kits. The curriculum on the CDs will help students apply algebraic concepts more effectively while giving them a glimpse into the world of engineering. Many opportunities and challenges have been encountered during the initial implementation of the program.

The goal of this project, sponsored by the National Science Foundation, is to increase student enrollment and student diversity in college engineering programs throughout the state of Maryland and, potentially, throughout the country. The program incorporates five objectives in order to attain this goal: (1) develop CD curriculum kits that target different fields of engineering (chemical/mechanical, electrical, and civil/mechanical) that can be used in both middle and high school algebra classes; (2) provide a summer workshop for in-service mathematics teachers and undergraduate engineering Teaching Fellows; (3) 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; (4) 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; and (5) 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. This paper presents results of the development of the fluid mechanics and electricity CDs.

MOTIVATION FOR THE PROJECT

It is often difficult for algebra students to see the application of mathematics beyond the word problems that they have in class. The motivation for the current project was to help students see the application of simple algebraic equations to engineering problems. If students can see the

wider applications of algebra, perhaps they will not only continue with advanced level mathematics, but will seek other areas to apply mathematics such as science and technology education. These applications will be sensitive to the interests of females and other underrepresented groups and will generate enhanced awareness among all students.

Massachusetts has been highly successful by fostering collaboration between the Tufts Center for Engineering Educational Outreach and the Massachusetts Department of Education.[1] While Massachusetts is much further along in their integration of engineering into the classroom, there are lessons to be learned in their program development that will benefit this project. Another mathematics related project, Adventure Engineering, uses engineering-based curricula in middle grade science and mathematics classes.[2] The Adventure Engineering project focuses on problem solving and the engineering design experience. A third project saw engineering graduate students assisting high school mathematics teachers in developing hands on approaches for algebra and trigonometry classes.[3] These laboratory activities were incorporated into the normal lesson plan. Both high school students and teachers benefited from using laboratory activities to demonstrate specific principles such as linearity and trigonometric functions.

Adding new engineering courses to the curriculum is a luxury that most school systems can not afford. With the addition of so many new basic requirements for middle and high school students, it became apparent that the best way to impact students would be through the existing curriculum. Algebra is a perfect companion to engineering.

PROJECT DEFINITION

CD Development

The main focus of the project is the development and evaluation of the engineering/algebra CDs. CDs were selected as the medium for the development and dissemination of curricula for this project because of their ability to be easily replicated and disseminated. Project materials, such as magnets and copper wires, will be packaged as part of a kit, but could easily be assembled by the teacher if needed. A team of college faculty and middle/high school teachers continue to work together to develop and test the CD kits that will provide simple hands on experiments. Students participating in the experiments can make observations about physical phenomena that can then be explained mathematically. The engineering applications in these CD kits relate to Maryland State high school requirements for instruction in algebra/data analysis and are easily incorporated by algebra teachers. Further, the curricula supports a Maryland state initiative that will require all Maryland students to pass a high school assessment in algebra/data analysis in order to graduate from high school beginning in 2007.

Each CD kit will be designed to be used in Algebra I classes, which are taught in both middle and high school. These materials will be challenging yet fun and interesting for both groups of students. The CDs will correlate to the expected algebraic knowledge of students at the end of each of the four nine-week sessions that compose the public school academic year. Materials will cover five class periods but will be modifiable for gifted or developmental classes and adaptable for the varying class lengths experienced in middle and high school. All curricula will address the required content standards for algebra/data analysis for the state of Maryland, focusing specifically on 6.0 through 10.0, the more challenging standards shown below.

Standard	Content	CD application
Knowledge of Number Relationships and Computation (6.0)	Students will describe, represent, and apply numbers and their relationships and will estimate and compute using mental strategies, paper/pencil, and technology.	Students will be able to demonstrate a knowledge of number relationships and computation in conjunction with the process standards: problem solving, communication, reasoning, and connections.
Process of Problem Solving (7.0)	Students will demonstrate their ability to apply a wide variety of mathematical concepts, processes, and skills to solve a broad range of problems.	Students will be asked to apply simple and complex computations to challenging, thought provoking questions, speculations, investigations and explorations.
Process of Communication (8.0)	Students will demonstrate their ability to organize and consolidate their mathematical thinking in order to analyze and use information, and will present ideas with words, symbols, visual displays, and technology.	Communication plays an important role in helping students make the connections between previously learned and newly acquired knowledge. Explaining, justifying, predicting, and defending ideas orally and in writing can clarify understanding of concepts and principles and can provide opportunities to assess understanding and thinking.
Process of Reasoning (9.0)	Students will demonstrate their ability to reason mathematically, using inductive and deductive reasoning and understand the difference. Students will justify and draw conclusions.	Reasoning, analyzing and thinking logically are essential to knowing and doing mathematics. Constructing valid arguments in problem settings and evaluating the arguments of others are important skills to be developed over time through a variety of experiences. Working in small groups will build teamwork and require communication and openness to new ideas.
Process of Connections (10.0)	Students will demonstrate their ability to relate and apply mathematics within the discipline, to other content areas, and to daily life.	Connections help students view mathematics as an integrated whole rather than an isolated set of topics. Building connections with engineering will help students acknowledge the relevance of mathematics, both in and out of school. Acknowledging the contributions of men and women from diverse cultures to the engineering field will also help to break down social barriers to involvement in engineering.

As an example, the Fluid Mechanics CD kit begins with a discussion of air pressure, followed by a number of simple hands on experiments taught by undergraduate Teaching Fellows. All applications would focus on materials or situations experienced by students in their daily lives. Research indicates that this connection is particularly important in generating the interest of girls and women.[4] An example follows.

Initial Exploration:

- 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 Kool Aid or punch.
    2. A straw with a couple of pin holes punched in halfway up the straw resting in a paper cup of Kool Aid or punch
    3. A straw inserted through a cork or one-holed rubber stopper into a 125mL Erlenmeyer flask containing Kool Aid or punch
    4. Two straws and a cup of Kool Aid 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. 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 a 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.)*

The discussion on air pressure is followed by a discussion on buoyancy. Finally, Bernoulli's equation is introduced through a number of hands on activities.

Initial Exploration:

- Suspend two apples, or ping pong balls, about 3 cm apart from a horizontal support. Ask the students what they expect will happen if they blow in between the apples. Do this experiment and observe the results. *(The apples will move closer together rather than farther away.)*
- 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. 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.)*

Concept:
In each of the above examples the key ingredient was the pressure of a moving fluid. The fluid common to all three examples was air, however other fluids also demonstrate the same properties we encountered above. Daniel Bernoulli proposed that there is a relationship between the speed of a moving fluid and the pressure it creates. Bernoulli's principle states that as the speed of the fluid increases the pressure in the fluid decreases. Simple algebraic formulas will be constructed around the activities. Upon completion of these experiments, the Teaching Fellow would introduce an important algebraic concept used in engineering. In this case it would be Bernoulli's equation:

$$Z_1 g + \tfrac{1}{2} V_1^2 + P_1/\mathrm{rho}_1 = Z_2 g + \tfrac{1}{2} V_2^2 + P_2/\mathrm{rho}_2$$

Where Z = the distance in the z direction
g = the standard acceleration of gravity
V = velocity
P = pressure
rho = density

After learning to manipulate the Bernoulli equation, students will be led on to discuss how airplanes fly. They will learn through both hands on observations as well as theoretical equations. The application of these equations to the set of experiments can be related to the Algebra/Data Analysis Content Standards sections 6.0, 7.0, 8.0, 9.0., and 10.0. This will be achieved by having the students analyze each of the experiments that were done, and identify how Bernoulli's equation relates to each of the problems. All curricula will be developed to create a clear connection between the algebraic concepts and the engineering application as suggested below.

MSDE Goal	Description	CD Kit	Learning Objective	Evaluation Method
6.0	Knowledge of Number Relationships and Computation	Fluid Mechanics	Calculation of terms in Bernoulli's equation; understanding the connection between and importance of a variable and a "real world" value.	Experimental observations, and lab assignment, assessment tool.
7.0	Process of Problem Solving	Fluid Mechanics	Determine information needed or missing to solve equations. Use a computational spreadsheet to generate velocity vs. pressure; analyze results.	Experimental observations, use of reference materials, and lab assignment.
8.0	Process of	Fluid	Analysis of observed results of the	Experimental

	Communication	Mechanics	experiments would be graphed to give a visual display of observations. Description of the reasoning process predict/analyze each successive experiment.	observations, lab assignment and pre-experiment prediction.
9.0	Process of Reasoning	Fluid Mechanics	Prediction of results of some experiments based on previous results. Ask the students to apply Bernoulli's equation to other phenomena.	Experimental observation, lab assignment, and post experiment analysis.
10.0	Process of Connections	Fluid Mechanics	Identify relationship between numbers and graphed data. Identify examples of fluid flow and how it works in their everyday life.	Experimental observations, lab assignments and post experiment analysis.

Prior to using the curriculum in the classroom, teachers will review each CD kit extensively. For instance, 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. Class time in these training programs will be used to gather input from the teachers on all aspects of the materials prior to using them in the classroom. This feedback will be incorporated into the development of the product.

Teacher Training

The faculty team will present a four-day workshop to introduce the field of engineering to middle/high school mathematics teachers in order to help them encourage and prepare students for a career in the engineering profession. In this workshop, teachers will explore the spectrum and reach of engineering in society. Participants will also learn what a college engineering curriculum entails, including the mathematics requirements, and what makes students successful in engineering. Finally, teachers will be educated about those elements that would increase the interest of underrepresented groups in engineering as a career. Teachers will participate in the "hands on" engineering projects described in the CD kits. They will also be paired with an undergraduate Teaching Fellow to begin developing a working relationship.

The course will cover the following topics:

- An introduction to the broad field of engineering
- Opportunities and rewards of an engineering career
- Overview of the freshman engineering design course
- Student panel discussion on what it takes to be an engineering student
- Tour of UMBC's engineering facilities
- High school preparation for an engineering career, including math and science
- CD kit review, critique, and discussion for implementation in the classroom
- Engineering faculty panel discussion on various engineering disciplines
- Use of the Internet to learn about engineering

- "Hands on" projects to help introduce middle/high school students to engineering
- Engineering research pursuits
- Success strategies that students might use in their pursuit of an engineering career
- Issues and answers for encouraging females and other underrepresented groups to consider a career in engineering

Each day teachers will be involved with alumni panels, hands on activities, review of after school programs (such as Future Scientists and Engineers of America (FSEA) and Hands On Science), success strategies for students, tours of engineering facilities, and methods of using the internet to extend engineering learning activities.

The teachers will be required to incorporate the algebra/engineering curricula learned in the workshop into their classrooms at the end of the workshop. They will then attend three additional follow-up days, one each semester and one the following summer, to help evaluate and revise the curricula. The teachers will also be asked to participate in a culminating event located at UMBC with their algebra students. An activity will take place in an engineering lab on campus to help students become familiar and comfortable with a university campus and understand the excitement and opportunities available in a course of study and career in engineering.

Through the workshop and the use of the CD kits, the teachers will gain a better appreciation of engineering and the kind of preparation needed for a career in engineering. Similarly, in the current project, there is opportunity for teachers to be exposed to current areas of research in engineering through presentations made by faculty during the summer workshops. These teachers will have the chance to tour labs of researchers and make connections for future research endeavors. The middle and high school students will also have an opportunity to view current engineering research when they tour the labs during the culminating activity. While there is no formal mechanism in place, both teachers and students are encouraged to develop relationships with the engineering faculty in order to become more aware of the types of things that engineers do. Middle and high school teachers can have a significant impact on a student's choice of career. By being given an awareness and appreciation for mathematics and engineering at an early age, students are more likely to choose higher-level mathematics and science courses that can better prepare them for college.

Undergraduate Teaching Fellows Program

Teachers will be assisted in the classroom by Undergraduate Teaching Fellows. Undergraduate engineering students will be selected and provided a stipend to support the program. Their responsibilities will include working with teachers during the summer workshop, supporting teachers in their initial implementation of the new curricula, and supporting the evaluation of the CD kits by gathering data from the students. The Teaching Fellows will also take a major role in the development of engineering after-school programs.

The training and development of the Teaching Fellows will build on the Integrated Teaching and Learning (ITL) program, an established K-12 engineering outreach program at the University of Colorado at Boulder.[5,6] Students will be enrolled as Fellows as undergraduates in their sophomore and junior year to support the student's increased retention in engineering. The

program will particularly target women and other underrepresented groups to serve as Fellows to increase the diversity of role models in the schools. Students will be encouraged to enroll in pairs, as this increases the likelihood for their continued participation. ITL found that having two Fellows at one school works well. The student pairs will serve three schools each, deciding among themselves and the teachers during the summer workshop how best to provide the support needed. Some of the schools will already have after-school programs in place and will need less student support. The Teaching Fellows will gain a greater understanding of what they have learned in their engineering courses, improve their communication skills, and develop an appreciation for the educational process. Together these elements will enhance their retention.

After-School Engineering Programs

The mathematics classes may spark some students to continuing to learn about engineering careers and participate in engineering-related activities. Locally, the Baltimore Museum of Industry, host of the Maryland Engineering Challenges, provides an introduction to many fields of science, mathematics, engineering, and technology through rewarding and age-appropriate problem-solving activities. The Engineering Challenges in Maryland have evolved from a number of different initiatives from groups of engineers, educators, and people involved in the Baltimore Museum of Industry. Middle school students might build powered maglev models, straw bridges or a model hovercraft. Additionally, high schools students might be invited to design and build a wood bridge, robot, miniature cargo aircraft or model ship. The Engineering Challenge Series is sponsored by the Engineering Society of Maryland, the Technology Association of Maryland, and the National Aeronautics and Space Administration (NASA). Other opportunities involve the FSEA organization which provides science and engineering activities for middle school students. The Teaching Fellows will take a lead role in building these after-school programs.

Participation of Women and Other Underrepresented Groups

The September 2000 Report of the Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development (CAWMSET) stated that "Unless the SET (science, engineering and technology) workforce becomes more representative of the general U.S. workforce, the nation may likely face severe shortages in SET workers. Yet, if women, underrepresented minorities and persons with disabilities were represented in the SET workforce in parity with their percentages in the total workforce population, this shortage could largely be ameliorated."[7] One recommendation the Commission presented was the development of high quality mathematics and science curricula for the pre-college environment, developed at the state level. Additionally, the Commission recommended teachers be well-prepared to teach that curricula.

The Teaching Fellows and teachers will receive training to insure they support a climate for young women and other underrepresented groups while addressing the major barriers to learning that most often affect girls, but also have an impact upon other underrepresented groups.[8] The curriculum will address motivational barriers by providing a simple yet interesting and fun application of mathematics to help motivate all students. Unequal background preparation will be leveled by teaching mathematics in an engineering context while developing mathematical methods and other skills as the course progresses. Lack of social usefulness can be addressed by providing projects that show the connection of mathematics to engineering applications that are

in turn connected to everyday household objects. All CD kits will be developed with a module that highlights successful engineers from a diversity of backgrounds.

EVALUATION AND DISCUSSION

Teacher feedback is a critical aspect of the curriculum development. All curricula developed throughout the project will be assessed by the teachers who have been trained to use the curricula, teachers who have taught using the curricula, and the students who participated in the learning process. The information gathered will support modifications in the training of teachers and content of the educational materials. Further, teachers who have participated in the workshop will be interviewed to find out what they find to be useful about the educational materials, and any suggestions they have for improving the usability of the materials. They also will be asked for input about how the education of teachers might be improved. Finally, they will be asked how they specifically intend to incorporate the educational materials into their instruction. Teachers who have used the educational materials will be interviewed about their experience with the materials, and suggestions for improvement regarding the materials and training program will be obtained. These research activities will be designed to evaluate the project with reference to objectives 1 and 2.

Surveys and interviews of the Fellows will serve as another element of the evaluation. Fellows will provide subjective information about their enjoyment of the project, the identification of learning that has taken place, and their own understanding and appreciation of engineering in relation to education. A final element of the evaluation will be to observe whether student activities under objectives 4 and 5 are implemented. Evaluation for these objectives also will involve administration of questionnaires and/or interviews to students participating in the programs regarding desirable and undesirable characteristics of program activities.

The evaluation summary will use the results from several assessment strategies to determine if student outcomes have been achieved. The primary student outcomes are program participation and interest in engineering (including intentions to continue in the subject area), particularly among females and other underrepresented groups. Program participation will be measured by strategies such as sign-in sheets and direct observation. Direct observation will permit ratings of amount and quality of participation beyond mere attendance. Interest and intentions will be assessed by interview and questionnaire methods. This assessment will take place at the end of the students' participation in the program (i.e., at the end of the semester or year). With the help of the teachers, students will also be tracked to identify whether they take additional advanced mathematics courses, passed the high school assessment for algebra/data analysis on the first or subsequent attempts, and/or participate in an engineering after-school program. This data will be compared to students in algebra classes that did not use the curriculum.

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TARYN BAYLES holds a Ph.D. in Chemical Engineering and is a lecturer in the Department of Chemical/Biochemical Engineering at UMBC. She emphasizes practical applications from her industrial experience when teaching engineering courses. Most recently she developed, coordinated and taught a summer workshop, "Introduction to Engineering for High School Teachers and Counselors."

CLAUDIA MORRELL, Director of Planning and Grants for the Center for Women and Information Technology at UMBC, joined the University in August of 2001. In both this and her previous position at CCBC, she became familiar with and has worked to address the issues related to the lack of participation of girls and women in STEM programs. Her skills as a collaborator have been instrumental in building bridges between the two institutions.