INTRODUCING ENGINEERING IN MIDDLE SCHOOLS

Laura L. Kosbar

Abstract - The Engineering Your Future program is a collaborative effort amongst IBM, the Colorado School of Mines (CSM), and the Denver Public School system (DPS). As part of this project, an IBM researcher and undergraduate students from CSM visit 25 middle school science classes (~600 students) on a monthly basis to expose the students to various scientific, mathematical, and engineering concepts through hands-on investigations. Each teaching module is designed to engage students in interesting and relevant experiments which demonstrate scientific or engineering concepts that reinforce or enhance the standard curriculum. Repetitive interventions with each class are used to develop relationships between the middle school students, the outreach instructor, and undergraduate student “role models”. The four participating Denver middle schools all have high minority (>90%) low-income (>70%) student populations that have demonstrated poor performance on state standardized tests of mathematics and science.

Index Terms – K-12 Outreach, Science Enrichment, Undergraduate Teaching Fellows

INTRODUCTION

Several well-respected groups (e.g., National Council of Teachers of Mathematics, National Education Knowledge Industry Association, National Science Teachers' Association, and the U.S. Department of Education) have raised concerns about the low level of scientific and mathematical literacy that exists in society and in schools. Many of these concerns are based on results from national and international standardized achievement tests. For example, the Third International Mathematics and Science Study found that U.S. students are being outperformed by other nations' students in both science and mathematics [1,2]. Results from the National Assessment of Educational Progress (NAEP) suggest that U.S. students from low-income families are performing below their middle class peers in these same subjects [3,4]. These findings and concerns that they raise have resulted in a broad range of reform activities that are designed to improve the education that all students receive in mathematics and science in elementary, middle school and high school [5–9]. Additionally, teaching and learning standards have been developed in both science [10-12] and mathematics [13-14] as a foundation to support the reform process.

At the very heart of the current reform lies the belief that student learning occurs through exploration and problem solving. According to the American Association for the Advancement of Science [15], science instruction should include active hands-on exploratory activities that are interdisciplinary in nature. The National Science Board [2] has criticized currently available curricular materials in the following manner, “Few [curriculum materials] introduce real-world interdisciplinary problems and serve as the foundation for advanced placement courses, school-to-work transition courses, or the challenges of a liberal arts college education.

Middle school has been identified as a crucial period for either encouraging or discouraging students' participation and interests in mathematics and science [16]. During the middle school years, many students opt out of the academic classes that are prerequisites for advanced mathematics and science courses – both in high school and beyond. Students often make these decisions with little or no academic guidance. Over half of all students, and up to almost two thirds of minority students plan to drop mathematics and science at the first opportunity [17]. Only 55% of non-minority students and 33% of minority students have the appropriate skills in mathematics and science to ensure that their future job options will not be limited. Of even greater concern is the finding that only 6% of graduating minority high school students in the US have completed the appropriate course work to enter college as science or engineering majors.

Student attitudes towards a given subject also impact the fields that they will eventually pursue. In general, African American and Latino students are less confident in their abilities in mathematics and science, and less apt to recognize that these subjects are useful and appropriate to their lives, than are their Caucasian peers [16]. Programs, such as the one proposed here, allow students to build confidence in their scientific and mathematical knowledge during the critical middle school years.

STUDENTS

In this pilot program, the Denver public School system identified four middle schools – Horace Mann, Lake, Martin Luther King, and Smiley – as the initial participants. The schools were chosen in part due to their large minority and low-income student populations, and in response to their relatively poor performance on the state standardized math and science tests (Colorado State Assessment Program – CSAP). Data on student demographics and test performance can be found in Table 1. Data for the entire Denver Public

1 Laura Kosbar, IBM T.J. Watson Research Center, Yorktown Heights, NY 10598 kosbar@us.ibm.com

TABLE I
### Student Demographics

<table>
<thead>
<tr>
<th></th>
<th>Horace Mann</th>
<th>Lake</th>
<th>MLK</th>
<th>Smiley</th>
<th>DPS</th>
<th>CO State</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American</td>
<td>3.4%</td>
<td>3.2%</td>
<td>43.5%</td>
<td>76.3%</td>
<td>19.3%</td>
<td>5.7%</td>
</tr>
<tr>
<td>American Indian</td>
<td>0.8%</td>
<td>1.7%</td>
<td>0.1%</td>
<td>0.4%</td>
<td>1.2%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Asian</td>
<td>0.5%</td>
<td>1.5%</td>
<td>4.3%</td>
<td>0.4%</td>
<td>3.3%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>89.7%</td>
<td>87.9%</td>
<td>42.8%</td>
<td>15.4%</td>
<td>56.0%</td>
<td>24.3%</td>
</tr>
<tr>
<td>White</td>
<td>5.5%</td>
<td>5.7%</td>
<td>9.2%</td>
<td>7.5%</td>
<td>20.2%</td>
<td>65.7%</td>
</tr>
<tr>
<td>Free/Reduced Lunch</td>
<td>88.6%</td>
<td>92.2%</td>
<td>71.3%</td>
<td>74.7%</td>
<td>70.8%</td>
<td></td>
</tr>
<tr>
<td>English Language Learners</td>
<td>35.7%</td>
<td>31.8%</td>
<td>14.2%</td>
<td>4.5%</td>
<td>19.2%</td>
<td></td>
</tr>
</tbody>
</table>

### Performance on Standardized State Tests (% of students achieving proficiency or above)

#### 8th Grade Science

<table>
<thead>
<tr>
<th></th>
<th>Horace Mann</th>
<th>Lake</th>
<th>MLK</th>
<th>Smiley</th>
<th>DPS</th>
<th>CO State</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>3%</td>
<td>6%</td>
<td>11%</td>
<td>13%</td>
<td>19%</td>
<td>49%</td>
</tr>
<tr>
<td>2002</td>
<td>13%</td>
<td>9%</td>
<td>11%</td>
<td>12%</td>
<td>21%</td>
<td>50%</td>
</tr>
</tbody>
</table>

#### Performance by Ethnicity (2002)

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Horace Mann</th>
<th>Lake</th>
<th>MLK</th>
<th>Smiley</th>
<th>DPS</th>
<th>CO State</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American</td>
<td>---</td>
<td>---</td>
<td>9%</td>
<td>12%</td>
<td>13%</td>
<td>21%</td>
</tr>
<tr>
<td>Asian</td>
<td>---</td>
<td>---</td>
<td>18%</td>
<td>---</td>
<td>40%</td>
<td>51%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>12%</td>
<td>7%</td>
<td>8%</td>
<td>11%</td>
<td>11%</td>
<td>21%</td>
</tr>
<tr>
<td>White</td>
<td>---</td>
<td>18%</td>
<td>39%</td>
<td>---</td>
<td>53%</td>
<td>62%</td>
</tr>
<tr>
<td>Free/Reduced Lunch</td>
<td>12%</td>
<td>7%</td>
<td>8%</td>
<td>8%</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Not Eligible for Free/Reduced Lunch</td>
<td>16%</td>
<td>17%</td>
<td>17%</td>
<td>22%</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

#### 8th Grade Mathematics

<table>
<thead>
<tr>
<th></th>
<th>Horace Mann</th>
<th>Lake</th>
<th>MLK</th>
<th>Smiley</th>
<th>DPS</th>
<th>CO State</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1%</td>
<td>2%</td>
<td>5%</td>
<td>16%</td>
<td>14%</td>
<td>39%</td>
</tr>
<tr>
<td>2002</td>
<td>6%</td>
<td>4%</td>
<td>7%</td>
<td>10%</td>
<td>14%</td>
<td>39%</td>
</tr>
</tbody>
</table>

#### Performance by Ethnicity (2002)

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Horace Mann</th>
<th>Lake</th>
<th>MLK</th>
<th>Smiley</th>
<th>DPS</th>
<th>CO State</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American</td>
<td>---</td>
<td>---</td>
<td>6%</td>
<td>10%</td>
<td>7%</td>
<td>15%</td>
</tr>
<tr>
<td>Asian</td>
<td>---</td>
<td>---</td>
<td>18%</td>
<td>---</td>
<td>33%</td>
<td>26%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>6%</td>
<td>3%</td>
<td>6%</td>
<td>7%</td>
<td>6%</td>
<td>15%</td>
</tr>
<tr>
<td>White</td>
<td>---</td>
<td>12%</td>
<td>17%</td>
<td>---</td>
<td>38%</td>
<td>49%</td>
</tr>
<tr>
<td>Free/Reduced Lunch</td>
<td>6%</td>
<td>4%</td>
<td>6%</td>
<td>3%</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Not Eligible for Free/Reduced Lunch</td>
<td>10%</td>
<td>4%</td>
<td>10%</td>
<td>23%</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

--- indicates data not reported due to small sample size
*  indicates data not reported

School system (DPS) and the results from all of the participating schools in Colorado are included for comparison. The student populations from all four schools are composed of over 90% ethnic minorities, and between 70-93% are from low-income households that are eligible for free or reduced lunch programs. Approximately 30-36% of the students attending Horace Mann and Lake Middle schools are English language learners.

The CSAP test scores for 8th grade science and mathematics indicate the existence of a significant gap between the performance of the students at these schools and the scores of their peers in other Denver public schools. This gap widens when compared to the performance of all students in public schools in Colorado. The scores also indicate significant ethnicity and income-based performance gaps. Differences in performance are also evident at the district and state levels.

The schools were allowed to select the grade levels and specific classes that would participate in *Engineering Your Future (EYF)*. The students were primarily in the seventh and eighth grades. In the 2002/2003 academic year, the entire 8th grade class at Lake and Horace Mann participated in EYF. All of the 7th grade class at Smiley, 6 classes of 7th grade students at Martin Luther King, and two classes of 7th graders at Lake also participated. Similar, though slightly smaller groups of students from these four schools participated during this program’s initial year of operation (2001/2002), with the inclusion of a few 6th grade classes. In all, approximately 500 students participated in 2001/2002, and about 600 students are participating in 2002/2003.

### PROGRAM DESIGN

This outreach program is a collaboration between IBM (through its loan and financial support of the developer/primary instructor via IBM’s Faculty Loan Program), Colorado School of Mines, and the Denver Public School system. It was designed to introduce middle school students to the concepts of engineering, and to relate engineering applications to current middle school science curricula. To accomplish this goal, inquiry-based, team-oriented, hands-on activities were developed with the intent of engaging as well
as instructing the participants. The students were encouraged to ask questions and “think outside the box” about both the principles they were learning and applications to science, industry, and their own lives.

A single intervention strategy was expected to be less effective in at-risk populations; hence this program was designed to include multiple interactions with the students. As such, classroom interventions were spread throughout the year, at approximately one-month intervals (~ 7 classroom interventions over the course of the academic year). The modules were designed to augment the current curricula without significantly impacting teachers’ existing lecture schedules.

The classroom interventions were unusual in that rather than just providing activities to the teachers, they brought a group of “resident experts” into the classroom – including a college professor with extensive experience in industry and several undergraduate students currently enrolled in a variety of engineering programs. One of the intents of the program was that middle school students would be exposed to individuals who were currently pursuing or participating in careers in science or engineering and might act as role models in these fields. It was determined through questioning the students that few of them knew any engineers or scientists and they had little idea of what careers in such fields entail.

In addition to the in-class modules, the program included several “special events” to generate student enthusiasm and expand their exposure to science and engineering. All of the students were invited to the Colorado School of Mines for a one-day field trip. This event included a tour of campus (many of the students had never visited a college campus and have few family members who have participated in higher education), science and engineering demonstrations including hands-on activities, and interactions with additional faculty and students.

The final event of the program encourages a bit of role-reversal – the students become the teachers. During the final in-class session, each team of students focuses on one of the modules covered during a previous session with the intent of learning how to teach this material to others. Depending on the choice of the students/school, this teaching experience may occur during an evening event at which the student’s parents are invited to be the audience, or the students may teach another, non-participating class at their school. In either case, the students experience both excitement and pride through sharing their knowledge of science and engineering with others. When the parents attend these student demonstrations, information is provided to the families about the high school coursework that will be expected of students who are interested in attending college and majoring in science or engineering – preparing the parents to act as informed advocates for their children.

**MODULES**

Seven different modules have been developed for this program. Each module was designed to be taught within one (~50 minute) class period, with suggestions for additional assignments and follow-on activities. The subjects of the modules were selected to a) supplement topics normally covered in the middle school science curriculum, and b) introduce the students to ways in which science and engineering directly impact their lives. The modules were intended to be interdisciplinary (e.g. acids and bases were explained from a chemical point of view as well as related to the acid/base chemistry of the body and the formation and effects of acid rain on the environment). The materials used for each module were primarily ones the students would be familiar with in their daily lives (diapers, plastics, household cleaners, foods such as lemons or soda pop, etc). Modules included *Introduction to Engineering, Acid/Base Chemistry, Polymers, Sound, Light, Environmental Chemistry, and Algorithms*. Due to space constraints, only two of the seven will be briefly described below. More detail on each of the modules can be obtained by contacting the author.

**Introduction to Engineering**

Most of the students participating in this program initially had little or no concept of what an engineer is, or what types of activities they might engage in. As a way of introducing the students to various aspects of engineering investigation and design, a discussion was initiated about the diverse fields of engineering, and the types of responsibilities, projects, or products that might result from engineering efforts. Differences in approach and expectations between pure science and engineering were also discussed.

To provide a more concrete example of what engineers do, and the type of approach they may take to problem solving, the class was told that they were all going to be “hired” as engineers for our new (and very temporary) company. (Note: it was usually worthwhile to immediately dispense with salary questions by indicating that this was a *profit sharing* company that must make a profit before any salaries would be paid – but this may also be used as an incentive for good engineering work, or to lead into a discussion of current salary ranges for engineers). The students were generally very excited about the idea of working as engineers on a real product. It is best to use a product that the students are familiar with, one that is inexpensive, and easy to disassemble. A product that fits well with these criteria is a disposable diaper [18].

The students were organized into teams or “departments”. Each department was responsible for evaluating appropriate functional criteria for our product, and reporting their proposed criteria to the rest of the company. This activity promotes critical and creative thinking by the students. The concept of *brainstorming* may
be introduced to the students as well as its utility in engineering design applications.

A company-wide list of product specifications was generated by combining the best ideas from each department. This list was used to evaluate a “competitor’s” product – such as a name-brand disposable diaper. The students were encouraged to evaluate the existing product using traditional experimental techniques (hypothesizing as to the function of given materials, construction techniques, etc. and then performing experiments to evaluate the accuracy of their hypotheses). A discussion of engineering and scientific literature – learning from what others have already discovered or created - can be useful at this point. The students were encouraged to record their observations about the types of materials used in the diaper construction and their probable purpose. They were encouraged to investigate the moisture absorption capabilities of the various layers of the diaper, including the small crystals or powder that are found in many diapers.

Most commercial diapers contain crystals or a powdered form of a “superabsorbing” polymer – generally sodium polyacrylate. This polymer can absorb up to 800 times its own weight in distilled water. The properties of this material were further investigated by adding other substances to the water or the fully hydrated polymer to determine if they impact the absorption of the polymer. Ionic substances, such as salt, will bind to the polymer more strongly than water, causing the polymer to release some of the bound water. Non-ionic substances, such as sugar, will have no impact on the water binding characteristics of the polymer. Discussions of the chemical properties of the materials involved and how these properties affect chemical interactions and materials performance may help students place these concepts in context relative to other topics in their curriculum.

The students responded enthusiastically to the opened and exploratory nature of this module. They enjoyed the sense of discovery and relationship to real world applications, materials, and techniques.

Polymers in our world

Polymers have become indispensable to chemical engineers and materials scientists for applications including fibers, films, containers and packaging, structural materials, and even automobiles. Polymers are ubiquitous – in our world and even in our bodies. The broad range of applications in which both mankind and nature employ polymers make them a fascinating topic for middle school students. Their structure and functions can be used as jumping off points for discussions of chemistry, materials properties, and even biology and biological functions.

Polymers have unique properties due to their long chain-like structure. Class discussion as to the applications of man-made polymers (or plastics) allowed the students to generate a list of “functional” properties that make polymers valuable engineering materials (strong, tough, flexible, resistant to breaking, light weight, low cost, etc.). While an explanation can be given of how the flexibility and entanglement or crosslinking of polymer chains leads to many of these properties, the students were most easily introduced to these concepts through “personal experience”. The students were taken to a relatively large open area (such as a hallway) and initially instructed to behave as “unassociated” small molecules, such as water. This led to a (necessary) discussion about the energetics of molecular motion and collisions and the effect of temperature on those energetics. Highly energetic collisions were disallowed in our “human” molecular system. It was best to start the student “molecules” off at relatively low (energetically speaking) temperatures, and ascertain that all molecular motions would stop when the instructor defined that the temperature had reached absolute zero. The students quickly realized that individual small molecules have a significant degree of mobility and freedom of motion.

The restrictions placed on the motion of individual molecules once they have combined to form linear polymer chains became evident when the students were linked (by holding hands or short lengths of cloth or rope) into chains containing 812 “monomers”. When the linear polymer chains were allowed to move, the students directly experienced the effects of coordinated motion on the individual monomers in the chain. Discussions or demonstrations of the non-Newtonian properties of polymer solutions (with spaghetti as a visual model) could easily be introduced at this point.

The final part of this learning exercise involved “crosslinking” the student polymer chains. This was most easily accomplished by having teachers and the undergraduate assistants act as bonds connecting different linear chains. It was worthwhile to point out initially that the crosslinked network that had just been formed was in a relaxed state, and the bonds had some flexibility and mobility. Once the students were allowed to move, the network generally got stretched such that many or most of the bonds became fully extended. The students were introduced to the idea that what they had just become a part of was essentially a “human rubber band”. Some of the responses of rubber bands to stress or stretching can actually be demonstrated with this human rubber band model.

This activity assists the students in gaining a practical understanding of the forces and interactions in polymers (both linear and crosslinked) that produce their unique structural properties relative to other materials. The students also gain a rudimentary understanding of some of the factors that must be considered in materials choices for given applications such as fibers, food containers, and the rubber on the soles of athletic shoes.

Hand’s on activities performed to reinforce and build on the previous activity included challenging students to pass a wooden skewer through an inflated balloon and creating and evaluating the properties of crosslinked polymers made from
glue or polyvinyl alcohol and borax. The students were capable of extrapolating from their “human polymer” experience to predict basic properties or the implications of varying crosslink density on real materials [19].

IMPLEMENTATION

Engineering Your Future was designed to be easily implemented at low cost to the schools. The materials required for each module can be obtained from local grocery, hardware, department or discount stores. A few items may be more readily found through laboratory equipment suppliers. The intent was to design inexpensive activities that could be replicated throughout this, or any other school system. The total materials cost for this program to date (covering two academic years and involving about 1100 students) has been under three thousand dollars.

While these modules can be performed by teachers alone, it has been our experience that the additional influence of the students and faculty member from a nearby university (CSM) significantly enhanced the impact of the program. Collaborations between industrial partners and school systems would also be expected to provide successful partnerships.

PROGRAM ASSESSMENT, OUTCOMES, AND FUTURE PLANS

The relative newness of the Engineering Your Future program precludes the availability of data on the long term impact of the program. However teachers, students, and even parents have given positive feedback on the program’s effectiveness in increasing the student’s interest and excitement about science and engineering.

Both teachers and students eagerly anticipated the CSM visits. Many teachers reported that their students would repeatedly ask when the next visit would occur. In several cases, the students would actually keep track of the timing of the interventions, and inform their teachers of the day we were expected to return. Teachers also reported that at parent/teacher conferences parents would comment on their children’s excitement about the program and the experiments that they had performed. Teachers also reported that the students learned and remembered the concepts covered during our visits far better than those covered during their normal classes – even compared to classes where the teacher had, themselves, used experiments or demonstrations. The reference “do you remember the experiment we did with the people from CSM” generally brought an instant response from the students. We will be performing student and teacher evaluations of this program at the end of the 2002-2003 academic year.

Long term assessment of such a program would be the ideal test of its effectiveness, especially observation of impacts on student learning, retention, and the ability to apply their knowledge. One measure would be improved performance on standardized tests. It is interesting to note that the two schools in which 8th graders were involved last year (Lake and Horace Mann) had increased CSAP scores in the 8th grade science examination (Table 1). The schools in which the 7th graders were involved (MLK and Smiley), where we had no involvement with the 8th graders who took last year’s test, did not demonstrate any increase. Obviously, the differences in test scores may be due to natural fluctuations or a variety of other sources, but it will be of value to follow any trends in the performance of the participating students in future years.

As a follow-on to this effort, an NSF grant is currently funding the development of a program that will combine a summer teacher training workshop with the in-class interventions. This program is entitled Engineering Our World, and the first teacher workshop will be held during the summer of 2003. Engineering Our World will include formative and summative assessments of both teacher workshop activities and in-class instruction. The results of this program will be presented at a later date.

CONCLUSIONS

This paper has presented a description of Engineering Your Future. In this program a visiting faculty member and undergraduate students from the Colorado School of Mines participated with four Denver middle schools to introduce engineering and scientific concepts into middle school classrooms. This program was designed to emphasize a hands-on, inquiry-based approach to learning. The activities encouraged group participation, critical thinking, and scientific reasoning. Relationships between the professor, undergraduate students, and the middle school participants were encouraged through a multiple intervention strategy over the course of the academic year. Responses from teachers, students, and parents indicate positive impacts on student interest in science and engineering.

ACKNOWLEDGMENT

I would like to acknowledge the contributions of Catherine Chess on the original development of the experiments included in the modules described above. I would also like to acknowledge the Minority Engineering Program at Colorado School of Mines for supplying the operating expenses and initial contacts required for Engineering Your Future. The students at CSM have been enthusiastic and devoted supporters of this program, volunteering their time, energy, and ideas – such a program would not have been possible without their unflagging efforts. Barbara Moskal and Cathy Skokan are fellow PI’s on the Engineering Our World project currently under development, and have contributed their ideas, time and energy to the continuation and expansion of this program. Finally, I would like to
thank IBM’s T.J. Watson Research Center for supporting my participation in IBM’s Faculty Loan Program, which allowed me to develop and implement Engineering Your Future at the Colorado School of Mines. IBM’s Faculty Loan Program is intended to promote underrepresented minorities pursuing careers in science and technology.

REFERENCES


