Engineering Our World: A Middle School Teacher Intervention

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Abstract

The *Engineering Our World* project was funded by the National Science Foundation and was a collaborative effort among the Colorado School of Mines, the Denver Public Schools, the Cherry Creek Schools and the University of Colorado at Colorado Springs. This pilot project provided intensive training and career development to middle school in-service science and mathematics teachers that focused on engineering and its relationship to science and mathematics curricula. A feature of this program was the inclusion of both a teacher summer workshop and monthly follow-up classroom visits. Three instruments were used to examine the effectiveness of the summer workshop for improving the participating teachers' knowledge of engineering. First, all of the participating teachers completed a background survey that described their college education with respect to science, mathematics and engineering. The second instrument was a pre-post content assessment that was developed by the project investigators in collaboration with the evaluator and that addressed the concepts presented during the workshop. The final assessment was a self-report instrument on the workshop activities. The results of this study suggest that not only did participating teachers' knowledge with respect to engineering improve as a result of the summer workshop, but also the teachers used their knowledge of engineering to supplement their science and mathematics classrooms.

I. Introduction

In the report, *Before It's Too Late*[1], the National Commission on Mathematics and Science Teaching for the 21st Century describes the education that United States students receive in science and mathematics as follows, "In an age now driven by the relentless necessity of scientific and technological advance, the current preparation that students in the United States receive in mathematics and science is, in a word, 'unacceptable'". This report is not isolated in the concerns that it raises. In fact, the National Council of Teachers of Mathematics, National Education Knowledge Industry Association, National Science Teachers' Association, and the U.S. Department of Education all 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 standardized achievement tests in which U.S. students are repeatedly outperformed by other nations' students in both science and mathematics[2,3].

These findings and concerns that they raise have resulted in a broad range of reform activities[4, 5, 6, 7, 8] within the U.S. that are designed to improve the education that all students receive in science and mathematics in elementary, middle school and high school. Teaching and learning standards have been developed in both science [9,10,11] and mathematics [13, 14, 15, 16] 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 (AAAS)[17], science instruction should include active hands-on exploratory activities that are interdisciplinary in nature. The National Science Board (NSB)[3] 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. Most innovative science curricula, for instance, seek coherence, integration, and movement from concrete ideas to abstract concepts. Unfortunately, traditional teacher education has not prepared teachers to design instruction in a manner that is consistent with these goals."

Adding to this problem is the large number of teachers who are providing instruction in a field other than the field in which they were certified. During the 1993-94 school year, Ingersoll[18] found that 27% of mathematics and 18% of science public school teachers were not certified within the field that they taught. Teachers who are teaching outside of their fields are unlikely to have the content knowledge necessary to create problem centered, interdisciplinary learning environments[18, 19]. Furthermore, the majority of practicing teachers completed their teacher preparation courses long before the current reform began. According to Kirwan[20], the average teacher in the U.S. has been out of school for more than 20 years. These teachers as well as their less experienced peers need to be equipped with new, relevant examples of science and technology in society.

Engineering Our World (EOW), which was funded by the National Science Foundation (EEC 0230702) and was a collaborative effort among the Colorado School of Mines (CSM), the Denver Public Schools (DPS), the Cherry Creek Schools (CCS) and the University of Colorado at Colorado Springs (UCCS), was designed to respond to the concerns discussed above. This pilot project provided intensive training and career development to middle school in-service science and mathematics teachers that focused on engineering and its relationship to science and mathematics. A feature of this program was the inclusion of both a teacher summer workshop and monthly follow-up classroom visits.

Thirteen in-service teachers attended the two-week summer workshop in 2003. Eight instructional units that incorporated introductory engineering and science concepts were developed and presented to the participating teachers. These units included concepts from chemical, mechanical, electrical, environmental and civil engineering. These units were also designed to address the content standards for science and mathematics curricula that are prescribed by the state of Colorado (see http://www.cde.state.co.us/index_stnd.htm). The modules that were developed as part of the in-service teacher component are currently being adapted for an elective course in engineering that will be offered to pre-service teachers at UCCS School of Education. This paper is focused solely upon the results of the in-service teacher program.

II. Goals

This paper focuses upon the following two goals of the in-service teacher component of the EOW project:

1) To introduce engineering subject matter and its relationship to traditional middle school science and mathematics curricula to middle school teachers through a summer workshop.

2) To provide teachers with a sustained experience that aids in continuous improvement and innovation throughout the school year.

III. Methods

A. Subjects.

Thirteen middle school teachers participated in the summer workshop. Six teachers were female. In the prior academic year, eight of the teachers taught science and four taught mathematics. One male participant was a substitute teacher who worked in both science and mathematics. Several teachers worked with more than one grade level - six, six, eight and one of the teachers taught in 6^{th}, 7^{th}, 8^{th}, and 9^{th} grade, respectively.

B. Summer Workshop

All of the participating teachers attended a two-week summer workshop that focused upon how engineering topics were related to middle school science and mathematics curricula. This workshop began at nine a.m., ended at four p.m. and allowed an hour for lunch each day. An outline of the topics addressed in this workshop is displayed in Table 1. Eight units were designed and presented to the teachers that incorporated not only introductory engineering and science content and knowledge, but also addressed the content standards for science and mathematics curriculum prescribed by the state of Colorado (detailed information with suggested grade level expectations can be found at http://www.cde.state.co.us/index_stnd.htm). Engineering fields, such as chemical, mechanical, civil, electrical, computer, and environmental, were discussed along with related science topics, such as chemistry (including the properties of elements and compounds, and acid/base chemistry) and physics (including heat, forces, electricity). The mathematics that was addressed included arithmetic, basic geometry, rational numbers, graphing and basic statistics. Each of the units was designed to be interactive and hands-on.

	9:00 – 10:00	10:00 – 12:00	1:00– 2:00	2:00 – 4:00
Monday	Pre-test	Introduction to workshop. What is engineering? Diversity in engineering	Review of various fields of engineering via discovery activity by participants (phone books and web search Presentation of fields of engineering.	Hands-on activity – Diaper Dissection; How to introduce middle school students to engineering.
Tuesday	Engineering design process vs scientific method	Introduction to assessment	Textbook exercise – how engineering fits in middle school math/science curriculum	Assessment : Introduction to scoring rubrics and open ended tasks – write diaper assessment
Wednesday	Civil Engineering	Map making exercise	Computer investigations of assessment websites	Bridge design and strength
Thursday	Chemical engineering	Hands-on activity – modifying materials properties of crosslinked polymers	Materials and their relationship to chemical structure	Lesson Planning on civil engineering utilizing inquiry-based techniques and introduction to writing classroom objectives
Friday	Field trip – visit NREL to observe engineers in action	Field trip (cont.)	Lesson Planning and assessment based on field trip	Continue lesson Planning and assessment based on field trip; give presentation to class
Monday	Environmental Engineering	Hands-on activity – identifying acids and bases	Discussion of acid/base chemistry in nature Demonstration – making smog and acid rain, and how to avoid making them…	Importance of chemistry in nature, and how engineers try to minimize human impact
Tuesday	Electrical Engineering	Series and parallel circuits	Motors and how they work	Lesson planning from electrical or mechanical experiments
Wednesday	Mechanical Engineering	Simple Machines	Web site sharing	Heat transfer and building an energy efficient home
Thursday	Student Final – Energy Audit	Measurements of temperature, water volume, room size, window size, etc	Impact of measurements on energy conservation	Lesson planning on energy audit
Friday	Field trip – visit local industry to observe engineers in action	Field trip (cont.)	Presentation and Discussion of “real-life” engineering	Summary, course evaluation, post-test

Table 1. Outline of Summer Workshop

For example, at the end of the first day of the workshop the teachers completed a unit called "Diaper Dissection". This unit was designed by Dr. Laura Kosbar, an IBM researcher, with the purpose of introducing middle school students to what engineers do. The unit begins with an explanation of the similarities and differences between engineering and science. To exemplify these differences, a hands-on activity was completed. First, the teachers were informed that they were part of a new company that would be manufacturing disposable diapers. Next, they were separated into teams or "departments", and each team was encouraged to perform the following engineering activities: 1) brainstorm a list of required properties for the companies product, 2) share their ideas with the other "departments" and create a "company-wide" set of requirements, 3) "reverse engineer" competitors products to evaluate the number and types of materials used, material properties, construction techniques, and whether these products met with their companies requirements. In order to complete the third step, the teacher teams examined and dissected diapers that are available in today's market. They soon discovered some common features. For example, there is a layer of material that separates the baby's skin from the absorbent layer of cotton-like material. The teachers speculated that this layer would keep the baby's skin dry and prevent diaper rash. This observation was tested and confirmed by pouring water through the diaper. They also discovered small crystals embedded within the cotton-like material. These crystals appeared to soak-up the water that was poured through the diaper. The workshop instructor identified these crystals as a super absorbent polymer (polymers would be discussed and explored in more detail in a later workshop unit). The teachers continued the experiment by measuring the maximum amount of pure water that could be absorbed by the polymer and comparing it to the polymer's absorbency using various water/sugar and water/salt combinations. Connections were then made to the middle school mathematics curriculum by discussing how the results could be used to calculate the concentrations of mixtures and the relative amount of liquid absorbed by the polymer based on different concentrations. Graphs could also be created to describe the absorbency of the polymer with respect to various concentrations.

C. Academic Year Follow-up

Summer workshops are useful tools to increase teacher's understanding of engineering, scientific and mathematical concepts. Unfortunately, without appropriate follow-up, such knowledge can fall prey to the pressures of daily teaching loads. In order to assist with and assure the implementation of this series of engineering units, the second phase of this program occurred during the academic year. A CSM faculty member visited each participating teacher one day each month during the fall semester. These visits served multiple purposes. For the teachers, these visits provide encouragement to utilize the engineering and science content covered during the summer workshop. They also provide a "resident expert" in the classroom that was used to answer questions both from the teachers and students. After the observation, the teacher and faculty member discussed the effectiveness of the given lesson and how the lesson could be improved for future instruction.

D. Assessment Instruments

Three instruments were used to examine the effectiveness of the summer workshop for improving the participating teachers' knowledge of science, mathematics, engineering and instructional pedagogy. First, all of the participating teachers completed a background survey that described their college education with respect to science, mathematics and engineering. The second instrument was a pre-post content assessment that consisted of twenty-seven multiple-choice questions. This instrument was developed by the project investigators in collaboration with the evaluator and was designed to measure concepts addressed during the workshop. Teachers completed the pre-content assessment on the first day of the workshop and the post content assessment on the last day of the workshop. A copy of this instrument is not included in here because it is being used to evaluate related projects. Making this document available on the web or as an appendix could compromise the integrity of the results of these related projects. The interested researcher may acquire a confidential copy by contacting the first author of this paper (bmoskal@mines.edu). The final workshop assessment instrument was a self-report instrument concerning workshop activities.

Two methods were used to evaluate the effectiveness of the follow-up classroom visits. At the end of the first semester, the teachers were contacted by the evaluator and briefly interviewed about the supports they would need in order to continue implementing what they had learned in the classroom. Also, a wrap-up meeting where teachers discussed their successes and failures was held at the end of the semester.

IV. Results

A. Background Survey

Eleven of the teachers completed a survey that detailed their background with respect to science, mathematics and engineering. All of the teachers had completed algebra in high school and four had also taken this course in college. One teacher had never had trigonometry or calculus. Of the remaining teachers, three had taken trigonometry only in high school, three only in college, and four in both college and high school. Of the two teachers who had taken calculus in high school, one had also completed this course in college. The remaining eight teachers had completed calculus only in college. All eleven teachers rated themselves average or above average in their knowledge of computational and conceptual mathematics.

The teachers were also asked to rate their knowledge within various areas of mathematics and science. The scale was: very weak, weak, adequate, strong and very strong. For algebra, the responses ranged from adequate to very strong. For trigonometry and calculus, the responses ranged from very weak to strong. The responses for engineering ranged from very weak to adequate. The median ratings for algebra and earth science were strong. For trigonometry, physics, chemistry, and physical science, the median rating was adequate. For calculus and engineering, the median rating was weak, with engineering receiving the highest number of very weak ratings. Only one teacher had previously taken an engineering course. All of the teachers indicated that they felt that it was important or very important for students to understand the relationship between mathematics and science and between mathematics and engineering. .

B. Pre-Post Content Assessment

Ten teachers completed the pre and post content assessment, which contained 27 multiple choice questions. A paired t-test was used to determine whether the average number of correct responses increased from pre ($\bar{x}_{pre}$=14.8) to post ($\bar{x}_{pre\ post}$ =19.4) assessment. Due to the small sample size, it was necessary to examine the assumptions of the paired t-test. A probability plot was used to verify that the distribution of the difference scores was approximately normal. Since the teachers completed the assessments individually, the independence assumption was also met. A significant difference was found (p=.002, one tailed paired t-test), suggesting that the teachers' knowledge of engineering concepts had improved as a result of the summer workshop.

C. Self-Report Instrument.

All thirteen teachers completed the self-report instrument. Eleven of the teachers agreed that the content was presented in an understandable manner. Twelve of the teachers indicated that the activities were useful. Although the majority of teachers indicated that the hands-on activities were the most useful, they differed as to the specific activities that were most useful. For example, some teachers identified the bridge building activity as their favorite while others indicated that this was their least favorite. The value assigned by a given teacher to an activity appeared to be strongly influenced by the personal skills and teaching responsibilities of that teacher. Suggestions were also made for improving future implementations of the workshop. These included: a greater focus on foundational skills and on mathematics.

D. Follow-up Interview.

Eleven teachers responded to the follow-up interviews. Two interviews were completed over the phone, four teachers provided written responses, and the remaining teachers were interviewed in person. Six teachers indicated that they would require further support to implement the project activities in the classroom. Of these teachers, one said that he did not have enough time to plan, implement and clean up the labs (hands-on activities) that were discussed in the workshop. Another teacher had intended to use some of the workshop units in her class, but when the fall semester started she learned that her two semester course had been cut to a one semester course. This eliminated the time that she needed to implement anything beyond the prescribed curriculum. Two teachers also mentioned that they did not have enough classroom supplies to implement some of the workshop activities. Two other teachers requested help with electricity and magnetism and one of these teachers also wanted to have more activities tied to sixth grade mathematics and science standards.

E. Wrap-up Meeting

In addition to the interviews, eleven of the teachers attended a wrap-up. During this meeting, the teachers presented both their successes and their failures. Although three of the teachers had not yet used any of the materials or activities due to required curricula or other constraints, all of the teachers indicated that they were planning to use the materials in the spring semester. The mathematics teachers indicated the greatest challenge in implementing the workshop activities was having time to fit them into an already over crowded curriculum.

Three of the teachers also shared exciting news, either in the interview or at the meeting. One teacher had been elected by her peers to participate in a Teacher Learning Project. She explained that the resources that she had acquired and used from the workshop had helped her to stand out as a leader. Another teacher had decided to work with a high school to create a middle school chapter of the high school's prestigious engineering institute — the workshop was credited as having exposed him to the appropriate engineering concepts. The third teacher told of how a class full of gifted, but at-risk students was transformed by his use of the engineering activities from the workshop. Grades increased and late assignments were no longer a major problem.

V. Conclusion

As was discussed at the start of this paper, there is currently a national need to improve the science and mathematical knowledge of K-12 students. The AAAS, NSB, and the NCTM agree that the most effective manner for improving student learning in science and mathematics is through the regular use of hands-on problem solving activities in the classroom. Unfortunately, most in-service teachers have not received the appropriate content or pedagogical training to implement these types of activities in their classroom. The purpose of this project was to provide the participating teachers with content and pedagogical training in the use and implementation of hands-on learning in the science and mathematics classroom. Additionally, practical examples of how mathematics and science is used in the world were provided through connections to engineering.

The results presented in this paper support the effectiveness of the workshop and follow-up classroom visits for attaining the project goals. Overall, the pre and post assessment results suggest that the participating teachers' knowledge and understanding of the content presented during the workshop had improved. Also, the majority of the participating teachers, through a self-report instrument, indicated that the workshop activities had been useful and appropriate to their classroom needs. Responses to the follow-up interview and the wrap-up meeting further support that the majority of teachers either had used the workshop materials in their classroom or intended to use these materials in their classroom within the next semester.

There was some variation in the participating teachers' responses to the different units. For example, some teachers indicated that the bridge building activity was their favorite activity while others indicated that this was their least favorite activity. These differences in response are not surprising. The participating teachers had diverse educational experiences, as was indicated by the background survey, and taught two different subject areas. Prior experiences as well as how well a given activity fits into curriculum are likely to influence a given teacher's favorite activity.

The additional assistance that the teachers requested at the end of the program was also not surprising. Lack of time, not enough classroom supplies, and an overcrowded curriculum are common problems throughout the K-12 curriculum. Two of the teachers also requested more instruction on electricity and magnetism and one teacher wanted to see more activities that were specific to sixth grade science and mathematics standards. This feedback will be used to refine future implementations of this workshop.

One of the major successes of this project was the effectiveness of the collaboration that was established between CSM, DPS, CCS and UCCS. Although not discussed here, UCCS is currently implementing the developed units as part of the pre-service teachers' curricula. The success of such a project suggests a collaborative model for future interventions. This project included two universities, CSM and UCCS. CSM provided experts in mathematics, science and engineering content, while UCCS provided experts in science and mathematics pedagogy. DPS and CCS provided teachers that were interested and excited about changing the way they taught.

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