K-12 Outreach in an Engineering Intensive University

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Abstract

The Colorado School of Mines has been active in seeking and receiving educational grants from a variety of sources, such as the National Science Foundation, Colorado Commission on Higher Education, and the Colorado Department of Education. Over the past three years, four funded projects have focused on providing middle school teachers with instruction in mathematics, science, and engineering content and pedagogy. Careful attention has been given to coordinating these projects in a manner that maximizes their impact on the broadest population of teachers and students. A selection of summer workshops and classroom interventions has been developed and tested. Additionally, ten graduate teaching fellows, drawn from the Departments of Mathematical and Computer Sciences, Engineering, Geophysics, and Environmental Science, have been trained to provide direct support to middle school teachers and students during classroom instruction. These fellows have collaborated with participating teachers and faculty in preparing and implementing innovative, hands-on mathematics, science, and engineering curricula. This paper describes the coordination of the four outreach projects and the impact that these projects are having on the educational community.

Introduction

Based on the results of standards tests[1,2], a number of 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 regarding the low-level of performance in mathematics and science that has been witnessed in the U.S. Students from low-income families are at an even greater risk of displaying weak mathematical and scientific knowledge when compared with their middle class peers. These findings and concerns that they have raised have resulted in a broad range of reform activities, including the passing of the "No Child Left Behind Act" (NCLB).[3]

NCLB was approved by the U.S. Congress in December 2001, and was signed into law by President George W. Bush in January 2002. NCLB is designed to hold schools accountable for the academic achievements of their students[3], and has been cited as the most challenging educational reform act since the Elementary and Secondary Education Act of 1964[4]. The core of NCLB is to provide measures designed to close achievement gaps between different groups of students[5]. In addition, NCLB requires states to develop and implement annual assessments in mathematics and reading in grades 3-8 and at least once in grades 10-12 by the 2005-2006 academic year. Beginning in 2007-2008, schools must administer annual tests in science achievement, at least once in grades 3-5, 6-9, and 10-12[6]. To ensure teacher quality, "teaching out of field" is no longer acceptable. States must ensure that all teachers who provide instruction in the core academic subjects of reading, mathematics, and science are "highly qualified" within their respective content area by the end of the 2005-2006 academic year. To be "highly qualified", teachers must match the following criteria: 1) have full state certification or pass the teacher licensing exam within the content area that they teach; 2) have a license to teach within the given state; and 3) not have had the license or certification waived. In addition, the law requires all new and existing elementary and middle school teachers to have at least a bachelor's degree[7].

In response to the NCLB and the requirements to be highly qualified, the U.S. government and the various states have made funds available to support in-service teachers in upgrading their mathematical and scientific knowledge. Faculty and graduate students at the Colorado School of Mines (CSM) have been actively involved in developing and implementing programs that support teachers in this endeavor. CSM is well known as an innovative leader in mineral engineering and applied science, and for excellence in both undergraduate and graduate engineering education. Although CSM does not offer degrees in education, it offers more science content-based teacher (K-12) recertification courses than any other institution in Colorado. Over the last three years, four projects have been funded, focusing on middle school mathematics and science content. This paper describes the philosophical design that underlies each project, project differences, and the impact that they are having on the educational community.

Philosophical Design

According to the American Association for the Advancement of Science, science instruction should include hands-on exploratory activities that are interdisciplinary in nature[8]. The National Science Board[2] has criticized currently available curricular material as follows, "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[9]." These same concerns are echoed in the literature that addresses mathematics education.

Each of the projects that are discussed in this paper are based on the philosophy that mathematics and science are related subjects that should be taught through hands-on experiences. The natural connection between mathematics and science is illustrated to participating teachers through engineering activities. Each activity is specifically designed to be linked to the Colorado State Departments' K12 Academic Standards for Mathematics and Science[10]. Brief descriptions of such activities are displayed in Figure 1. Additional examples can be found at http://www.mines.edu/research/k12-partnership.

Figure1. Brief descriptions of hands-on activities that illustrate the relationship between mathematics and science through hands-on, engineering activities

Activity: Voltage Divider **Description:** 1. The learners are provided with instruction on how to calculate the resistors that are necessary for constructing a simple circuit. 2. The resistors and battery are measured to calculate deviations from the ideal. 3. A simple circuit is constructed on a proto-board and the output voltage is measured to verify circuit and calculations. **Mathematical Standards:** 1. Using algebraic methods in problem solving situations 2. Using data collection in problem solving 3. Using tools for measurement purposes **Scientific Standards:** 1. Understanding the process of scientific investigation and design 2. Conducting, communicating about, and evaluating these investigations 3. Knowing that energy appears in different forms and can be moved and changed 4. Using a model to predict change	**Activity:** Toothpick Bridges **Description:** 1. The students learned types of bridges, especially truss bridges, and how they work. 2. The students saw how bridge construction requires engineering and mathematical knowledge and skills. 3. The students learned why triangles form strong structures. 4. The students built and tested a toothpick truss bridge. **Mathematical Standards:** 1. Using number sense and algebraic methods in problem solving situations 2. Using geometric in problem solving 3. Using tools for measurement purposes 4. Linking concepts and procedure in solving problems **Scientific Standards:** 1. Understanding the process of scientific investigation and design 2. Conducting, communicating about, and evaluating these investigations 3. Knowing and understanding interrelationships among science, technology, and human activity and how they can affect the world.

Another critical component underlying these projects is that each is based at the middle school level. Middle school has been identified as a crucial period for either encouraging or discouraging students' participation and interests in science and mathematics[11]. During the middle school years, many students opt out of the academic classes that are pre-requisites for advanced science, engineering, and mathematics courses, both in high school and beyond. Over half of all students and up to almost two-thirds of minority students plan to drop science and mathematics at the first opportunity[12]. Only 55% of non-minority students and 33% of minority students have the appropriate skills in mathematics, science, and engineering to ensure their future job options will not be limited[12]. Of even greater concern is the finding that only 6% of graduating minority high school students in the U.S. have completed the appropriate course work to enter college as mathematics, science or engineering majors. In summary, in order to increase the number of students that continue their education into higher mathematics, science, and engineering, students' interests need to be captivated in these areas during the middle school years. Middle school throughout this paper is defined to be grades 6 through 8.

Projects

Each of the projects described in this section have the same primary purpose: to improve in-service teachers' knowledge and understanding of mathematics and science and, thereby, improve the instruction that middle school students receive in these same subjects. Figure 2 provides a timeline that indicates the funding period and duration for each of these projects. Each project directly responds to Rita Colwell's (Former Director of the National Science Foundation (NSF)) concern, "We cannot expect the task of science and math education to be the responsibility solely of K-12 teachers while scientists, engineers and graduate students remain busy in their university laboratories[13]". In other words, each of these projects includes the participation of college faculty members, graduate students, and middle school teachers.

Figure 2. Timeline of funding period and duration for each project

Project	Funding Period	Workshops to Date	Follow-up and Evaluation to date
Engineering Our World	September 30, 2002 – August 30, 2005	June, 2003	September, 2003 – May, 2005
Engineering In Middle School	March 1, 2003 – September 30, 2003	June, 2003	September, 2003 – October, 2003
Physical Science & Mathematics in Middle School	May 1, 2004 – May 1, 2007	June, 2004 July, 2004	September, 2004 – May, 2004
GK-12 Learning Partnership	January 2003 – January 2006	August, 2003 August, 2004	September, 2003 – May, 2004 September, 2004 – May 2005

Engineering Our World

This pilot program, which was partially funded by NSF (Award #EED-0230702) and began in January 2003, is currently in the final evaluation stage. Teachers from Denver Public Schools (urban), Cherry Creek School District (urban), and Jefferson County School District (suburban) attended a two week, six hour per day, summer workshop that was designed to introduce the relationships among various engineering disciplines and middle school mathematics and science. There were eight science teachers and five mathematics teachers. Five, six, and two teachers were from Cherry Creek, Denver Public Schools, and Jefferson County School District, respectively. The focus of the summer workshop was threefold: 1) to improve the middle school teachers' backgrounds of engineering disciplines and their relevance to physical science and associated mathematical concepts in their current curriculum, 2) to introduce the teachers to techniques for integrating content and learning standards (including content literacy) into the curriculum, and 3) to provide teachers with instruction concerning how to use inexpensive materials to provide hands-on learning experiences in their classroom. To help ensure that the summer workshop had an impact on the participating classrooms, Dr. Catherine Skokan, an

Engineering Professor at CSM, dedicated 40-50 hours each month (an average of 2 hours per classroom) visiting and assisting the participating teachers in their classrooms.
In parallel with this effort, the University of Colorado at Colorado Springs pilot tested a one-semester course for pre-service teachers covering the "Fundamentals of Engineering." The materials that were used for this course were the same as those that were used for the summer workshops. By combining this effort, both in-service and pre-service teachers benefited from the developed curriculum.

Engineering In Middle School

Based on *Engineering Our World*, a second project, called *Engineering in the Middle School*, was funded by the Colorado Commission on Higher Education, NCLB Professional Development Program. This project offered the *Engineering Our World* summer workshop to middle school teachers in Montrose County School District, a rural school district on the Western Slope of the Rocky Mountains, Colorado.

Fifteen teachers participated in this project. Since travel between Montrose and CSM is about 290 miles, faculty members from CSM could not complete the follow-up classroom visits during the academic year. Instead, two expert teachers, one in mathematics and one in science, were trained by CSM faculty to complete the follow-up monthly visits. These individuals, who were both high school teachers and adjunct instructors at Mesa State College- Montrose Extension, were identified by their district as expert teachers.

Physical Science & Mathematics in the Middle School Classroom

Physical Science and Mathematics in the Middle School Classroom is a current project that reflects an expansion of the concepts that were previously developed through *Engineering Our World* and *Engineering in the Middle School.* Through a grant from the CDE, this program includes teachers and students from eight school districts (six of which are considered to be high need), faculty from CSM, two CSM graduate students, a researcher from IBM, and a researcher from the Colorado Energy Science Center. In this project, as was the case with the prior projects, two week summer workshops were offered to middle school mathematics and science teachers. In the summer of 2004, 17 mathematics and nine science teachers participated in this project.

Although modeled after the previously discussed projects, there are some differences. First, during the morning session of the summer workshops, the mathematics and science teachers attended separate sessions that were specifically designed to provide instruction in their respective content area. The afternoon session then used materials that were developed for *Engineering Our World* and *Engineering in the Middle School* to illustrate the connections between mathematics and science and the applications within engineering.

Another difference within this project is that graduate students complete the follow-up classroom visits rather than a CSM faculty member. The reduced cost that results from this change allows more frequent visits to be made to the classroom. On average, the graduate students assist the teachers for a half of a day in the classroom every two weeks. The theme of this workshop was to improve teachers' mathematics and science content knowledge with a continued emphasis on engineering applications as in *Engineering Our World*.

GK-12 Learning Partnerships

Through partial funding of the NSF (DGE 0231611), CSM has received a three-year grant, *GK-12 Learning Partnerships: Creating Problem Centered, Interdisciplinary Learning Environments,* which began in 2003 and will continue until 2006. This project embodies a collaboration between Colorado Adams County School District 50 (Adams 50) and CSM. The focus of this project is similar to those that were previously discussed— to develop classroom learning environments that are hands-on and that illustrate how mathematics can be applied to science and engineering.

Similar to the previously discussed projects, the *GK-12 Learning Partnerships* project began with a teacher summer workshop. Unlike the prior workshops, this workshop was only eight days long and was attended by both participating teachers and graduate students. The graduate students were drawn from the fields of mathematics, computer science, engineering, and geophysics. During the first week of the workshop, the participating teachers attended sessions that were specifically designed to increase their content knowledge of mathematics, science, and engineering; graduate students attended sessions to increase their knowledge of pedagogy and the middle school classroom. This project also includes follow-up classroom visits. However, these visits are completed by the graduate students who provide direct assistance in the classroom to a given teacher for 10 to 15 hours each week of the academic year. In other words, this intervention is far more intense then interventions described in the prior projects.

Impact

Table 1 displays the number of in-service and pre-service teachers whohave participated in each of the previously described projects. Notice that several teachers in different districts participated in more than one program. This table also displays the number of graduate students and undergraduate students involved in the different projects. Assuming that each participating teacher impacts 100 students each year, we can estimate that these four projects have impacted more than 5,000 middle school students.

Table 1: Number of participants in each project

	Number of Participants					
Workshop	**Districts**	**Teachers**	**Pre-Service Teachers**	**K-12 Students (estimate)**	**Graduate Students**	**Undergrad Students**
Engineering Our World	3	13	15	1,500	none	none
Engineering In Middle School	2	10	0	1,000	none	none
Physical Science & Mathematics in the Middle School	6	25	0	2,500	2	1
GK-12 Learning Partnership	1	11	0	1,100	11	4
TOTAL	11	55	15	5,500	13	5

Project Feedback

At the end of each of the workshops, a self-report evaluation instrument was administered to the participating teachers. The majority of teachers indicated that the content was presented in an understandable manner and that the activities presented were useful. Only one teacher, across projects, indicated that he/she was undecided with respect to these two statements. The participating teachers were also asked to identify the most valuable activities of the workshops. The most common responses were the use of hands-on activities and the connections that were made between science and mathematics through engineering examples. The participating teachers also provided feedback for improvement purposes. For example, several teachers felt that the use of websites and that some of the activities were too difficult for the average middle school classroom. Overall, the majority of the teachers indicated that the workshop was a positive and valuable educational experience. General comments included: “Nice job”, “A great experience”, “What a great course! The best I’ve had since undergrad science courses”, “I overall loved this. This has been very helpful to increase my content knowledge in areas that I’m not comfortable in as well as offer activities that I could use in my classroom.”

As a follow-up assessment activity, we developed and administered a feedback survey in February 2005 to the teachers that are participating in the on-going projects, *Physical Science & Mathematics in the Middle School Classroom* and *GK-12 Learning Partnerships*. This instrument was designed to provide feedback concerning how the project activities directly impacted the classroom throughout the 2004-2005 academic year. Feedback acquired through this instrument will also be used to improve future summer workshops.

Table 2: Number of responses in each category for the follow-up feedback survey

Survey Question	**CDE Teachers (25 total)**				**GK-12 Teachers (8 total)**				**Comments**
	NAA	ALB	AGB	AGD	NAA	ALB	AGB	AGD	
How would you rate the extent to which your knowledge of engineering improved as a result of the workshop?	0	2	11	3	0	2	4	1	
To what extent did the engineering activities completed at the workshop impact the instruction you provide in your classroom?	0	3	10	2	1	1	4	1	
To what extent did your students benefit from the engineering knowledge that you gained by attending the summer workshop(s)?	0	4	9	2	0	1	6	0	
To what extent were you satisfied with the types of engineering exercises presented at the summer workshop(s)?	0	1	8	6	0	0	3	4	More middle school level activities that tie into state standards
To what extent do you feel that you have a better understanding of engineering now that you have completed the workshop(s)?	0	5	9	1	0	1	5	1	
Since the workshop(s), how much have you used engineering in classroom instruction?	3	7	4	1	0	2	3	2	* Bridge building * Voltage dividers * Graphing chemistry labs

Teachers were asked to answer the questions by selecting Not At All (NAA), A Little Bit (ALB), A Good Bit (AGB) or A Great Deal (AGD). The teachers also made comments or gave suggestions on free-response questions. Table 2 displays the results of this follow-up evaluation from the returned surveys. The survey also asked teachers to rate the quality of the information presented at the workshop(s) from Very Poor to Excellent. From the CDE workshop, nine teachers felt the information presented was Excellent and six rated it as Good. Six teachers from the GK-12 workshop gave a rating of Excellent, while one felt the information was Good. Of the 22 teachers who returned the survey, 20 have expressed interest in returning for future summer workshops. The teachers commented that the information was invaluable and the professors and graduate students are professional, knowledgeable, and a wonderful resource.

Summary

This paper describes the coordination of four outreach projects that have been or are currently being conducted at CSM. As the above discussion illustrates, lesson learned from earlier projects were used to improve the design of follow-up projects. These projects have directly influenced the educational experiences of 59 in-service teachers, 15 pre-service teachers, 13 graduate students, and four undergraduate students. Additionally, more than 6,000 middle school students have benefited from these programs. Each project had an underlying philosophical design that supported hands-on, active learning at the middle school level and the collaboration of middle school teachers, science, engineering, and mathematics faculty and undergraduate and graduate students in the development and implementation of middle school science and mathematics curriculum. Feedback acquired from participating teachers supports that the methods used were appropriate and effective. In response to follow-up surveys, many of the teachers commented on the useful on the hands-on activities and the important impact that these activities were having in their classrooms. Future research efforts will directly examine the impact that these programs are having on student mathematical and scientific learning as measured through the Colorado Student Assessment Program.

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