ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #15850

STEM Outreach: Capitalizing on Dissemination (Work in Progress)

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This work in progress provides examples of how engineering lessons developed as part of a K-12 Science, Technology, Engineering and Mathematics (STEM) outreach program at the Colorado School of Mines (CSM) have been created in a flexible manner that supports their adaption to multiple venues and grade levels. The design presented here simplifies the lesson creation process while supporting a broad dissemination to pre-college teachers and students. The importance of this effort is reflected in the research findings that many young students do not know what engineers do.[3] The proposed approach supports faculty and graduate students in maximizing the potential impact of their outreach efforts, reaching a broader population of young students.

Two specific lesson plans are presented, Mining Coal and Bridge Building. These lessons were selected because they illustrate flexibility in design and our initial efforts at embedding such flexibility. Although this outreach program has resulted in over 100 STEM lesson plans, many of these lessons have targeted individual grade levels. Efforts are underway to redesign these lessons using the approach described here. The majority of the adaptations are with respect to the mathematics involved. We have found that the engineering examples can be used at multiple grade levels as long as careful attention is given to the appropriateness of the underlying mathematics. This is illustrated in the examples that follow.

We begin with a presentation of the lessons. This is followed by a description of the program for which they were developed. Next, we summarize the various grade levels and venues in which they have been implemented, illustrating the broad impact outreach can have.

Lesson Plans

The first lesson plan, Mining Coal, is drawn from the field of Environmental Engineering. The second, Bridge Building, is from Civil Engineering. Both lessons require approximately one hour to complete and thus can fit in the time period allotted for most pre-college classes.

Mining Coal—Environmental Engineering

This lesson, which focuses specifically on coal, introduces students to the concept of environmental engineering. Thus far, more than 175 students in grades kindergarten through eighth grade have completed this lesson in a classroom setting or as part of a summer STEM camp. The lesson begins with a 15-minute introduction addressing coal and environmental engineering. Approximately 45 minutes is required for the hands-on component.

Coal is a sedimentary rock; therefore, this lesson matches many earth science curriculums that investigate rock types. Background information is provided about coal and how it is a non-renewable resource. Samples of coal, which are available free of charge from the American Coal Society, are passed around, allowing students to physically manipulate the coal. Next the discussion moves to where coal is found and how it is obtained. Coal can be mined either by underground shaft mining or mountain top removal. Mountain top removal has a severe impact on the environment and laws have been passed stating that mining companies must recover the land to a useable form after the coal has been mined.

This lesson involves students mining chocolate chips out of cookies with the chocolate chips representing coal. The lesson begins with students “purchasing” their choice of cookie and of chip extraction equipment, e.g. toothpick, paperclip, etc. These purchases and associated costs are recorded on a worksheet. Next, the cookie is placed on grid paper and the students draw a circle around it. They then "mine" out the chips and then recover the land by placing the crumbs back in the circle, representing land reclamation. Each chip that is mined is multiplied by a set value to determine profit. Each crumb that is not in the circle is assessed a penalty fee. Student must calculate their net profit, which is the amount of profit from mined chips reduced by the purchasing costs for the cookie and mining equipment along with any reclamation penalty. By varying the level of difficulty of the mathematics, this lesson can be adapted to various grade levels. Prices can be set as whole numbers or as fractions and decimals.

Building Bridges—Civil Engineering. The second lesson, which introduces students to civil engineering, has been completed by more than 300 K-6 students in several venues, viz, classrooms, summer camps, and elementary school science fairs. As part of this lesson students construct bridges out of gumdrops and toothpicks.

The lesson begins with a classroom brainstorming session concerning what makes a successful bridge and the importance of triangles and weight distribution. Students work in groups of three to five and are provided with 100 toothpicks and 50 gumdrops. These teams construct a bridge that spans 8 inches. A cup is placed on the bridge and coins are added until the bridge collapses. The winner is determined by which bridge can hold the most weight.

There are many variations and adaptions that can be made to this activity to adjust the mathematical complexity to students' grade levels. In the previous discussion, the winner is determined based on bridge efficiency or the amount of weight the bridge can hold before it collapses (load). This can be measured through a simple count of the number of coins or through a measurement of the weight of those coins. This can also be adjusted to include a ratio of the load weight to the weight of the bridge. Another adaption of this lesson is assigning "costs" to the gumdrops, toothpicks and coins that are used in the bridge construction. A ratio can then be formed between the mass of the coins and the cost of the materials used. The values used throughout this lesson can be adapted to be whole number or decimals and fractions.

Context of Program

The lesson plans described here were created and implemented as part of a university K-8 collaborative project. STEM graduate students or "fellows" were hired to assist elementary and middle school teachers in their classrooms. The program begins the summer before the fellowship with the teachers and fellows jointly attending a two-week summer workshop. CSM faculty instruct the workshop, offering content expertise and hands-on activities designed for K-8 classroom use. A key component of our programs is the use of hands-on engineering activities and demonstrations that teachers can directly use in their classroom.[6]

During the workshop, each fellow is paired with 2-3 elementary or middle school teachers with whom they work during the academic year. The fellows spend approximately 15 hours a week in the classroom assisting their partner teacher in STEM instruction. Fellows are compensated for their work through project coverage of their tuition, stipend and fees. Teachers and fellows collaborate during the workshop to design a lesson that they will use in a classroom. The lesson plans discussed here were created by a fellow/teacher pair. Based on their success, they have since been used in additional classrooms and revised for other venues, such as summer camps and science nights. These are further highlighted in the section title, "Outreach Venues."

Partnering STEM graduate students with teachers offers many advantages. Certified teachers are often well trained in the pedagogy of instruction, and are well prepared to manage the classroom and engage students in learning. They also provide a realistic understanding of the level of their students' knowledge and prior learning. Teacher feedback is essential to the successful adaption of lesson plans to different age groups. However, elementary and some middle school teachers are trained to be generalists in the fields that comprise pre-secondary instruction. This can limit their understanding of STEM content. Fellows offer rich content knowledge in their fields. Fellows benefit from being in the classroom by developing more effective communication and teaching skills.[2] This experience strengthens fellows' abilities to communicate in research teams and prepares future Ph.D.'s to offer effective college instruction. It has also been found that classrooms with a fellow report more positive attitudes with respect to science than those that did not have a fellow by the end of the year.[4]

Grade Level Adaptions

Fellows have many opportunities to implement the lesson plans that are presented at the workshop or that they themselves create with partner teachers. Table 1 (Coal Mining) and Table 2 (Bridge Building) describe the diverse manner in which the two previously discussed lesson plans have or can be adapted for different grade levels. Both lesson plans have been tested in grades K-6. Potential adaptions beyond these levels are provided in the tables as well. Engineering education at lower levels requires simple mathematics and hands-on activities; at the higher levels, lessons can be more complex, particularly with respect to mathematics, as student comprehension increases.[1] K-12 teachers are excellent resources for making decisions concerning such adaptations. Older students should be able to apply science and mathematics when solving engineering problems.[5] Altering the complexity of the mathematics provides a method to adapt engineering lessons to a wide variety of age groups.

Table 1. Coal Mining

Grade	Adaptation	Common Core Mathematical Concepts
K-2	Students can count the chips mined and compare with other students. Students can also construct a visual representation of the data by making a bar graph for the number of chips in each cookie.	Counting and Cardinality Measurement and Data
3-5	Students can begin to use the worksheet and determine costs and profits and apply addition, subtraction and multiplication skills, using whole number prices. Students can also calculate the area of their cookie by counting square on the grid paper on which the cookie was circled.	Operations and Algebraic Thinking Measurement and Data
6-8	Students can use the same worksheet; however, prices are now represented as decimal and fraction values.	The Number System Ratios and Proportional Relationships
High School	Students can develop their own worksheet, with prices determined by the teacher.	Number and Quantity Algebra Modeling

Outreach Venues

Each of these lesson plans has also been used in venues outside of the K-12 classroom. These include science nights, summer camps and programs for students with learning disabilities. Each is briefly discussed here.

Table 2. Bridge Building

Grade	Adaptation	Common Core Mathematical Concept
K-2	Students construct a bridge and the winner can be determined by the bridge that holds the most weight. Students can practice counting by counting the number of coins their bridge held along with the number of toothpicks and gumdrops used. Students can also compare their number of coins with other groups. A discussion can also focus on what shapes were used in their bridge construction and which shape can hold the most mass.	Counting and Cardinality Geometry Measurement and Data
3-5	The winner is determined by the bridge that can hold the most mass but is also the lightest. Students can use a calculator to determine their bridge efficiency.	Operations and Algebraic Thinking Measurement and Data
6-8	Gumdrops, toothpicks and coins are assigned values, student them multiply the materials and coins by values and divide the value of the coins by the value of the materials to determine which bridge.	The Number System Ratios and Proportional Relationships
High School	Students can weigh a single toothpick, gumdrop, and coin. Students can then multiply these values by the number materials used to construct their bridge and the number of coins their bridge held. Once these numbers are determined, the bridge efficiency can be calculated.	Algebra Modeling

<u>Science Night and Science Presentations.</u> Science nights are sponsored by the schools and the students and parents are invited to attend and participate in a variety of STEM activities. Fellows share hands-on STEM activities at these events, often drawn from the summer program. During these events, families rotate through stations; therefore lessons used at a science night must be completed in a relatively short period, usually within 15 minutes. This does not provide time for in-depth discussions, so quick activities are preferred. Because the audience at science night consists of students and their parents, multiple learning abilities must be supported. In such cases, keeping the mathematics component quick and simple is helpful. Presentations can also be made to groups of students and parents with the recommendation of “do try this at home.” All of the materials for the activities presented here are inexpensive and easily acquired.

<u>Summer Camps</u>. The program is also involved in summer camps in which the graduate fellows lead the instruction of STEM lessons. One camp is a day-camp designed for middle school students. During this camp, 3-4 fellows design, organize and lead STEM activities. Because this camp involves a grade range (6-8) rather than a single grade, adjustments for different knowledge levels are necessary. This can be accomplished by having graduate fellows working with students from the younger grade levels and assisting them in the problem solving. Additionally, groups can be designed where older students are paired with younger students.

<u>Learning Disabled Populations</u>. One of our outreach programs is working with dyslexic students, ages 7-13. Dyslexia is a language based learning disorder that makes learning to read

difficult. Some researchers believe that dyslexic students have enhanced capabilities in STEM. Our role in the camp is to provide the students with a break from reading in the form of a hands-on STEM activity. Both the Coal Mining and Bridge Building activities have been used with these students. The only adaptions that have been made for this population is that text is read aloud and the language used on worksheets is simple, and when possible, replaced with pictures.

Conclusions

Regardless of the grade level or venue, we found that the participating elementary and middle school students were able to successfully complete the primary engineering activity of the two lessons presented here. A key element to success was adjusting the mathematics involved in response to the students' knowledge. Adjustments were necessary even when our partner teachers evaluated the activities as age appropriate. One take-away from this program is that very young students can understand engineering concepts; the challenge is the mathematics involved. Mathematical concepts offer easy targets for lesson modification and do not require extensive alteration to key engineering concepts that are the focus of the lesson.

The outreach program described in this paper has resulted in well over 100 different STEM lesson plans. Disseminating these lessons across grade levels in the classroom and educational events outside the classroom is essential to maximizing their utility. Future work is needed to examine the extent to which the various lessons in the program can be adapted to a wide range of K-12 classrooms and venues. This approach to outreach offers the opportunity to impact the entire pipeline rather than limiting our influence to a few, individual grades.

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