Using Active Learning in Engineering Design Activities in Secondary High School Science Classes

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Presented at the 2006 AERA Annual Meeting

Abstract

This paper describes hands-on engineering design activities that were developed for high school science courses through Project STEP at the University of Cincinnati. These activities are built on the active learning model, involving a specific problem that is given to the students to solve through the use of engineering design principles. The design problem is centered on concepts the students learned in their classes, thus addressing specific educational standards. Additionally, the activities introduce engineering design to high school students with the aim of enhancing student learning and improving attitudes towards science and engineering.

Introduction

With the rapid increase of foreign competition for engineering and technology-related jobs, there is a strong need for a technologically savvy and broadly educated workforce in our country. Since these technology-related jobs are the driving force behind economic growth, our economic future depends on our ability to educate students in science, technology, engineering, and mathematics (Kumagai & Hood, 2005). Thus, methods for enhancing student learning and attitudes in these areas are of great importance to the public interest.

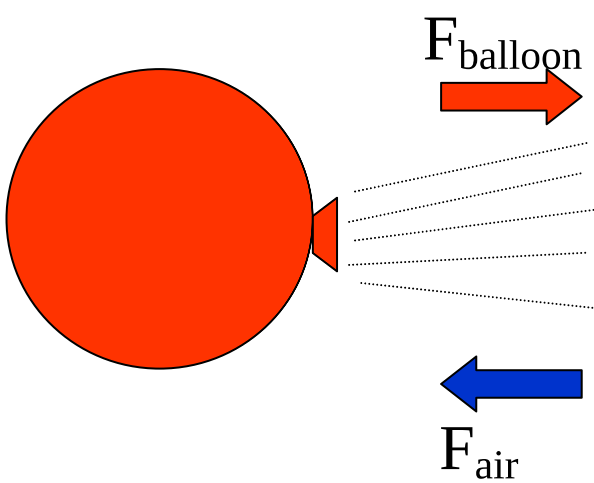
Toward these goals, the National Science Foundation has recently provided funding for pre-collegiate outreach activities through the GK-12 program. This article addresses one of the expected outcomes for K-12 students, enriched learning. Project STEP was formed in 2001 at the University of Cincinnati as a result of an NSF GK-12 award. Through this program, graduate students in the sciences, engineering, and education have worked with local area public schools in the design, development, and implementation of authentic learning activities. Two particular lessons, Balloon Powered Vehicle and Boat Float Challenge, are highlighted in this work. The lessons are described and results presented to show the impact of using active learning activities on student learning and attitudes toward science and engineering.

Recent research espouses active learning in the areas of science and mathematics. Lessons that use active learning emphasize making sense of a concept, using the newly created knowledge or schema in an attempt to complete a task, and self-assessing the results to make adjustments and improvements. These practices have been shown to improve student comprehension (White & Frederiksen, 1998; Schoenfeld, 1991) and ability to transfer their learning from one setting to another (Palincsar & Brown, 1984). By providing students the opportunity to take control of the activity, the learning becomes more important and meaningful to the student (Bransford, Brown, & Cocking, 2000). Therefore, an increase in student learning and attitudes toward science and engineering may be measured after the completion of an engineering design activity that incorporates active learning.

The activities were implemented with 53 students in a 9th grade Physical Science class and 24 students in 12th grade Physics class. The students were from a population that is at least 90% African American from a low socioeconomic background, with approximately half males and half females.

Activity 1 – Balloon Powered Vehicle

Engineers solve problems by designing solutions with a given set of constraints, such as performance and budget. To introduce this concept of engineering design, a lesson was developed to give students a hands-on experience to simulate real-world engineering design. At the time of implementation, the students in the 12th grade Physics class were studying Newton's laws of forces, so we developed an activity to also investigate Newton's 3rd Law, which states that for every action there is an equal and opposite reaction. A basic example of this law is the motion of an air-filled balloon when the air is allowed to escape (see Figure below).



The air rushing out of the balloon has a force that pushes against the surrounding air, which has an equal and opposite reaction force that pushes against the balloon, causing it to move forward. Thus an air-filled balloon can be thought of as a power source. Using this concept, students were given the task of designing a vehicle that is powered by an air-filled balloon. Additional constraints included the materials the students could use and the overall cost of their design. Each material was assigned a fixed cost (see table below), so the students had to keep in mind budgeting considerations when selecting from the available materials. All the materials used are inexpensive and easy to find in a craft store, thus simplifying the implementation of the activity.

Component	Unit cost	# used	Total cost
Balloons	100		
Straws	70		
Life savers	200		
Construction paper	50		
Tape	70		
Paper Clips	60		
Scissors	n/a		
Toothpicks	50		
Buttons	80		
Aluminum Foil	60		
String	50		
Totals			

The performance goals for the vehicles involved achieving the longest distance traveled while also maximizing cost efficiency. The students worked in pairs and participated with their classmates in a competition to determine the design that went the farthest, the most creative design, and the top overall in terms of cost effectiveness and distance. In order to enter their vehicle in the competition, each group had to fill out a design packet that included sketches, a written description of how the vehicle functioned and the physical principles used, and budgeting. The lesson took a total of 3 days, a total of 150 minutes of class time to implement.

Activity 2 – Boat Float Challenge

This lesson engages students through the task of designing a boat using a limited set of materials. As with the previous activity, the purpose of the activity we developed for the 9th grade Physical Science class was to introduce engineering design concepts to students while also investigating a learning standard for their content area. Just before we implemented this lesson, the students had been learning about density, so we focused our design activity on the use of density in the construction of a boat. As with the Balloon Powered Vehicle, design constraints included power source, materials, and cost. We again used very simple and cheap materials for the boat construction (see table below)

Students worked in pairs to achieve several design goals culminating with the Boat Float Challenge competition. Each boat was tested and awarded points for the following categories: (1) Distance traveled in a trough of water with one blow of air (provided by their science teacher); (2) Amount of weight the boat could hold (measured with 1 gram cubes); (3) Cost efficiency. In order to enter their boat into the competition, the students needed to complete a design packet. Whereas the 12th grade Balloon Powered Vehicle students were relatively on their own with regards to the design packet, we included checkpoints for the 9th grade students in this activity. Checkpoints are used to give the teacher the opportunity to review student work in the middle of an activity, helping to ensure they are progressing at an acceptable rate and with suitable work is being performed. This activity was implemented in six 50-minute class periods.

Component	Cost $	Check if used
Straws	100	
Aluminum foil	75	
Cardboard	50	
Styrofoam	200	
Craft sticks (wood)	50	
Scotch tape	50	
Glue	50	
Construction paper	30	

Impact and Results

In order to assess the impact of these two activities on student learning and attitudes towards science and engineering, quantitative and qualitative analyses were conducted. Two instruments, both paper-and-pencil objective tests, were used to measure the variables of cognitive achievement and attitude toward learning. For each class, a pre-test was administered to the students to assess their prior understanding of the concepts included in the lesson. The same test was administered following the lesson to determine whether learning took place. Additionally, a survey was given to the students after the lesson to determine the effect the lesson had on their attitudes toward science and engineering. Both descriptive and inferential statistics were calculated with all assumptions of the inferential testing met.

The expectation that there would be significant differences for achievement and attitude toward learning was met. In comparing the results from pre- and post-tests, statistically significant increases in average scores were seen in both classes on the post-test. The class average on the Boat Float Challenge pre-test was 25%, which increased to 66% on the post-test ($t = 9.32$, $p = .000$). Similar results were observed in the Balloon Powered Vehicle activity, which saw an increase from 56% to 76% ($t = 2.746$, $p = .014$). Additionally, the student feedback survey showed a marked effect on student attitudes. Many students reported an increase in their interest in engineering (58% and 36% in Physical Science and Physics respectively) and the majority of students reported that they felt more confident in their ability to learn science (83% and 80% in Physical Science and Physics respectively).

Anecdotal evidence support these achievement and attitude findings. Informal student reflections indicated that students really enjoy learning in this way. Student comments included:

<u>Boat Float</u>
“I liked that we were able to do some hands-on work that had us thinking.”
“I liked how we got to work at something, making a design of our own."
"I like that it gave us a chance to explore the engineering world."
“I liked building the boat and testing it to see if you need to make some changes.”
“I liked that it was hands-on. Also that it was my boat like I could make it any way I wanted to.”

<u>Balloon</u>
“I liked building and having a hands-on activity.”
“I liked assuming the role of an engineer and finding out what they go through when testing.”
“I liked that it was hands-on. It was fun because it made you think.”
“I liked having to create my own car, putting my own ideas to use.”
“I liked that we had to apply Newton’s law and that helped in creating our design.”

Lessons Learned

One of the important aspects of authentic learning is the use of situations that are familiar to the students. The opposite of this, of course, is the use of scenarios that students are largely unfamiliar with, which can reduce the significance of the activity to the students. In developing these lessons, we were sure to keep in mind things that would be recognizable for the students, so as to build on their prior knowledge. To facilitate this, we informally asked students in the 12th grade Physics class about their interests outside of school. The overwhelming majority indicated an interest in cars, which gave us confidence as we moved forward with the Balloon Powered Vehicle activity. Along the same lines, the concept of boats was used in the Boat Float Challenge because the students were very aware of similar weight-bearing barges that float past Cincinnati as they head down the Ohio River. Therefore, both activities were targeted to build on the students’ prior knowledge.

Another important characteristic of these lessons is the basic framework that can be applied in many other settings. These activities are centered around the concept of engineering design, specifically how to come up with a solution within a set of constraints. We have applied this framework to two lessons in different content areas and different grade levels and achieved similarly positive results. It is our belief that this framework can be used in the development of many other activities that target different concepts than the ones presented in this paper. All it takes is a little imagination; a few craft store supplies, and some enthusiastic students. Then again, the student comments show that the activities themselves generate enthusiasm among students, so you already have two out of three components!

Summary

While there is agreement that the field of engineering design has strong potential for the education of secondary science students, little research has been conducted to validate its full range of possibilities for enhancing cognition and attitudes towards learning. The results of this study show that hands-on engineering design activities have a positive impact on student learning and attitudes toward science and engineering. These activities are relatively inexpensive and easy to implement in science classes at all levels of secondary education. Additionally, the basic framework of these activities deals with engineering design in a broad sense. Thus these principles can be applied to numerous scientific concepts to create similar engineering activities that also incorporate the appropriate education standards.

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Acknowledgements

We would like to acknowledge the National Science Foundation (NSF) for supporting Project STEP through Grant #0139312 as well as and cost sharing funds provided by the Southwest Ohio Center for Excellence in Science and Mathematics Education and the University of Cincinnati. Any opinions, finding and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

We thank the teachers and students who participated in the STEP project, specifically Amy Jameson and Harry Voll at Shroder Paideia Academy for allowing us to work with them and their students in their classrooms. The original concept for the Balloon Powered Vehicle comes from a ZOOMsci activity involving a wind powered car using materials such as lifesavers, straws, paper, paper clips, and tape. We have expanded the lesson to include more materials, budgeting, design packet, and analysis questions. The original activity, The Puff-Mobile, can be found at http://pbskids.org/zoom/activities/sci/puffmobile.html.

Biographies

Michael J. Rust is a Ph.D. Candidate at the University of Cincinnati in the Department of Electrical & Computer Engineering and Computer Science. He received his B.S. in Electrical Engineering from the same institution in 2003. Rust has worked at semiconductor manufacturer Texas Instruments and medical device developers Ethicon Endo-Surgery and AtriCure. His current research interests involve the application of nanotechnology to medical problems, including nanobiosystems and lab-on-a-chip. He plans to go into teaching in higher education when he completes his degree. Email: rustmj@ececs.uc.edu.

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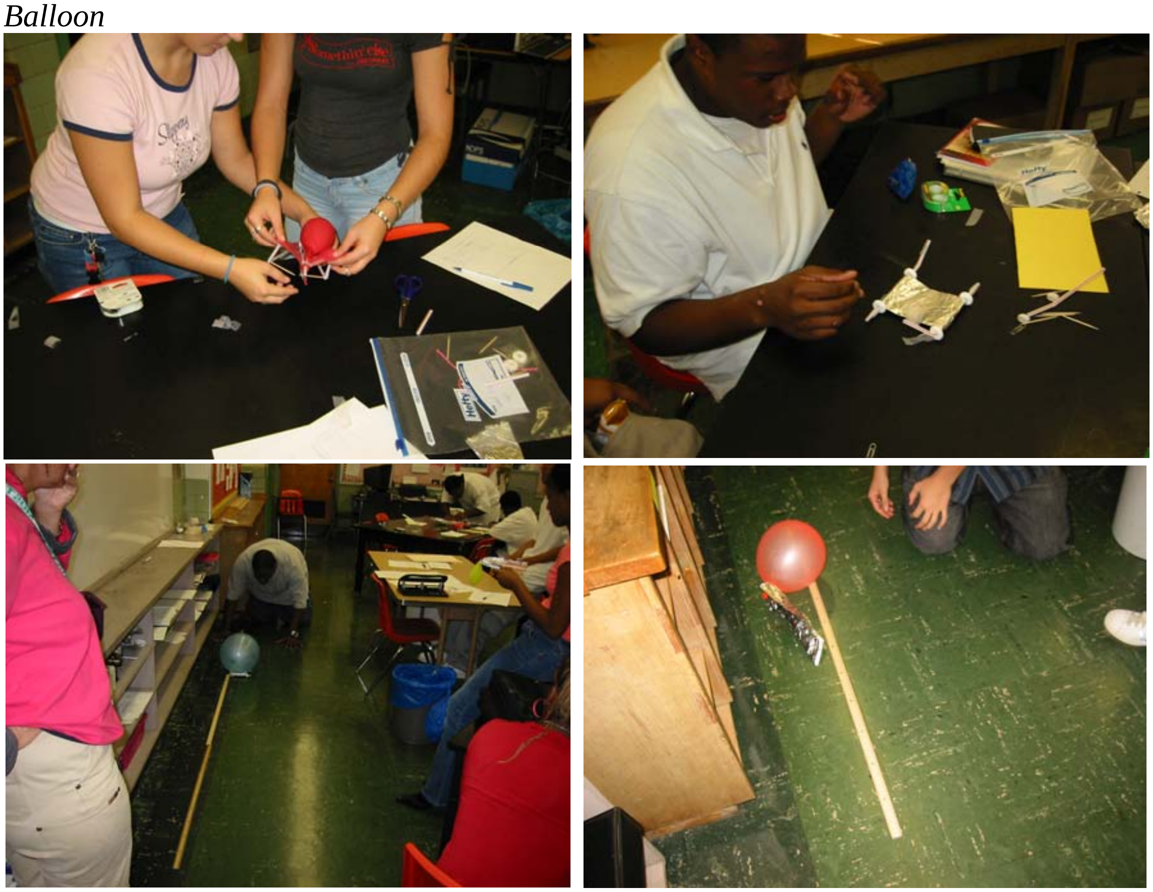
Appendices

Pictures of students doing activities and handouts from the lessons.

Balloon



Boat