AC 2009-451: INCORPORATING STEM CONCEPTS IN THE CLASSROOM THROUGH PROBLEM-BASED LEARNING

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Incorporating STEM Concepts in the Classroom through Problem Based Learning

Abstract

West Virginia University College of Engineering and Mineral Resources and The EdVenture Group have partnered successfully over the past four years to increase the awareness and classroom applications of engineering curriculum through technology with 7th-12th grade students across the state of WV. Math and Science teachers from across the state have collaborated with education consultants, industry professionals, graduate students, and one another to gain knowledge and create units that focus on STEM careers and curriculum. The units, known as TIME (Tools for Integrating Math and Engineering) Kits, are stored electronically on a free teacher resource site for use in classrooms across the country. *www.thesolutionsite.com*

The 12-hour units of instruction are developed during a week-long workshop that provides classroom teachers with the opportunity to work with engineering faculty, graduate assistants and industry experts. The model is based on providing time for teachers to learn, tools for teachers to use and strategies to assist them in focusing on and connecting engineering to STEM course work. By connecting university experts, industry experts and 7th-12th grade educators a new network has been created to link these groups and bring all areas of knowledge and application to classroom instructional units. All units are based on content standards, 21st century skills, and a problem-based learning approach and translate regionally to other states Pre and post-assessments are administered to students who take part in a TIME Kit unit to gauge the acquisition of math and/or science concepts as well as attitudinal data concerning engineering as a career choice. This paper describes a sample TIME Kit for illustration. The paper also shows how, over three years, the partners have overcome roadblocks in teacher training, which teacher incentives to use and which to avoid, and how to ensure a solid program evaluation.

1.0 Introduction

It is commonly known that the United States is not producing enough STEM (science, technology, engineering and math) undergraduates to compete in an increasingly global market. One common concern shared by college and high school administrators is how to educate high school teachers in math or science about what engineering is. Teachers report that they are reluctant to discuss engineering applications – not because they do not understand force, vectors, and chemical change, but because they simply did not have an engineering course in college or they don't know how similar engineering and pure science applications can be. Many times, we find that teachers are actually much closer to explaining engineering concepts than they think; once they build some expertise and confidence, they become enthusiastic about doing so.

At West Virginia University, a STEP (Science, Technology, Engineering, and Mathematics Talent Expansion Program) project called "Engineers of Tomorrow" began in 2005 to bring more Appalachian students, particularly rural students, underrepresented minorities and women, to engineering as a career path. This large-scale project brings together the College of Engineering and Mineral Resources, the College of Human Resources and Education, the College of Arts and Sciences, and The EdVenture Group, a private consulting and educational resource development company based in Morgantown, WV. As part of this STEP project, the idea for TIME Kits (Tools to Integrate Math and Engineering) was born as one of several interventions of the College of Engineering and Mineral Resources in an effort to fill the pipeline with WVU engineering graduates. Other interventions in the same project include a dedicated freshman recruiter, early intervention courses in math and physics to catch students with difficulties early in the term (rather than at the end when it's too late), an on-line freshman engineering course for high school students, a summer engineering camp, and a course for pre-service high school math teachers to learn about people who use math in their career, particularly engineers.

For Appalachian and minority students, high school girls in particular, economic prospects often appear better in the short term for students going directly into local industries (e.g., mining, logging). Many technical paths, such as engineering, that require college degrees appear less lucrative. Because the long term economic prospects for many of these Appalachian industries are limited, and because many low-tech jobs prospects are being outsourced, the real way out of dead-end or low-paying jobs is through a technical career path- especially engineering. We were sure that once teachers understood basic engineering processes and career options available, they would quickly realize they can make a change in their students' lives; they can make a difference in local families' lives. Their students could start their own technology-enhanced business. Their students could make a difference, period. The teachers just needed to know how to introduce their students to engineering. Where would we begin to train high school teachers about basic engineering content and career paths? The solution was the development of TIME Kits.

The primary force behind TIME Kits is to create web-based curriculum that has a solid foundation in math and science, but is immersed in an engineering context. A secondary goal is to meet teacher needs by addressing curriculum standards mandated by No Child Left Behind (NCLB) legislation and the West Virginia Department of Education's emphasis on 21st Century Skills (i.e., critical thinking, problem solving, interpersonal and collaborative skills, global awareness, financial and civic literacy).

2.0 TIME Kit Development

Each TIME Kit unit is developed by a certified math or science teacher during a summer development workshop. This intense, five-day workshop exposes teachers to practicing engineers, engineering professors, engineering career paths, and to technology tools needed to post the final Kit. In addition, the Kits integrate the use of 21st Century Skills and reinforce skill use in the classroom. Each teacher develops and tests a web-based unit that is ultimately posted to www.thesolutionsite.com www.thesolutionsite.com for teachers everywhere to use.

There are three stages to the development and implementation of the TIME Kits: the summer workshop, unit instruction, and research study. Each development stage is explained in the sections that follow.

2.1 TIME Kit Development: Stage 1: The Summer Workshop

The summer workshop begins with a local engineering professional explaining the need for engineers in society and generally what his firm does. This discussion engages teachers in a process that explains to high school teachers what engineers do and how they do it.

This conversation is followed by several WVU Engineering professors verbally painting a picture of the new face of engineering. An excellent example of this was the Disney World model. One professor explained the various engineering jobs found at Disney World including traffic routing, food and beverage operations, and capacity planning – all of which steer away from the stereotypical bridge building engineers. This really helped teachers to open their eyes to the engineering profession, which will directly influence their students' attitudes.

Following this panel-like discussion, teachers take on the role of student and participate in a simplified TIME Kit activity created prior to this workshop entitled "Building an Improved FEMA House." In this activity, teachers are introduced to a real-life engineering concern: designing a hurricane-proof but cost-effective, temporary, collapsible dwelling. Teachers first problem-solve as a small group, then design and prototype-build the most cost efficient hurricane-proof house with specific material, strength and cost constraints. After this two-hour exercise, the remainder of the first day of the workshop is spent touring WVU's engineering facility. The day culminates with a question/answer period led by WVU's College of Engineering graduate assistants.

For the remainder of the 5-day summer TIME Kit development workshop, the participants work with education consultants from The EdVenture Group to increase their understanding of today's students – world views and use of technology tools – in order to close the gap that exists between real-world and educational experiences, and then develop the "TIME Kit" engineering problem-based lesson plans. The education consultants introduce participants to problem-based learning, the application of Bloom's Taxonomy, authentic assessment, gaming, Google for Educators, social networking, blogging, podcasting, Moviemaker software applications, and the book *Teaching for Tomorrow* by Ted McCain. Each problem-based unit created is required to contain the following elements: 21st Century Skills, West Virginia Content Standards, National Standards, higher-order thinking skills, and authentic assessments. A great deal of importance is placed on aligning every lesson within a TIME Kit to West Virginia Content Standards. In order for classroom teachers in WV and across the country to use these in their classrooms, it is imperative for each lesson to interface with K-12 content in the classroom *and* mandated science and mathematics frameworks. The education consultants from EdVenture work one-on-one with each participant to ensure a full understanding of the workshop's curriculum.

Teachers work in groups to apply these educational principles and technology to develop a theme-based curriculum unit that employs math, technology, science, critical thinking, problem-solving methodologies, and other 21st century skills to solve a defined engineering problem. The

set of lesson plans that are created and formed into the curriculum unit, known as a TIME Kit, are then matched to state and national content standards for the targeted grade levels and to the list of 21st Century Skills so teachers who use these curriculum units can know which content standard each TIME Kit will meet.

Each unit is put through a three-step evaluation process: peer-to-peer evaluation with another teacher in the workshop; evaluation by a web development expert and engineering professor; and evaluation by a curriculum expert who evaluates the unit from a pedagogical perspective. After each unit passes all three evaluation steps, it is posted to the Solution Site. The Solution Site (www.thesolutionsite.com) was developed as part of a 1998 USDE Technology Innovation Challenge Grant. The site contains over 1200 units of instruction in all subject areas developed by teachers for classroom implementation. All units have been evaluated and tied to standards. The Solution Site is a free resource for educators across the world and averages 20,000 unique hits per month.

2.2 TIME Kit Development: Stage Two

Stage two is unit implementation where each teacher is responsible for implementing the unit in their own classroom. An education consultant from The EdVenture Group observes a portion of each unit being taught and then interviews the teacher asking, "What worked and what didn't work? What would you do differently? How did this activity impact student learning?" and several students asking, "What did you like or dislike about this activity? Did using technology help you understand the content better?" Teachers also administer a pre and post-assessment in each unit for analysis by WVU professors to determine the effectiveness of the unit from a content and engineering knowledge perspective. The data is used to make modifications to the unit for future use and planning for new workshops.

2.3 TIME Kit Development: Stage Three

Stage three is the ongoing research and program evaluation. Our goal for the 2009 workshop is to conduct a full field evaluation on every TIME Kit developed (20). Each teacher who implements a unit and a comparison teacher in that same school will conduct pre and post assessment of engineering content, math content, and student attitudes related to that unit. This evaluation design will allow us to examine whether learning and attitude changes differ among students who receive TIME Kit instruction compared to those who receive instruction typical at each school.[1]

3.0 Sample TIME Kits

The following example TIME Kits are presented to illustrate the types of engineering problems used, the format of the lessons and how each lesson is linked to the K-12 content standards.

3.1 Food Safety "Just Eat It" TIME Kit

Figure 1 shows the overview page for the "Just Eat It" curriculum unit that examines issues related to food safety. This TIME Kit requires students to develop an understanding of the

dangers of food borne illnesses and how food engineers are called upon to develop measures to ensure the safe production, preparation, and preservation of food products.

Time Kits

Tools for Integrating Math and Engineering

Overview - "Just Eat It"

Overview

Lesson 1

Lesson 2

Lesson 3

Standards

Authors: Heather Stickler

Subject(s): Science (Biology)

Grade Level: 10-12

Problem:

Food engineering refers to the engineering aspects of food production and processing. Food safety is a scientific discipline describing the handling, preparation, and storage of food in ways that prevent foodborne illnesses. Food can transmit diseases from person to person as well as serve as a growth medium for bacteria that can cause food poisoning (Wikipedia). In this unit students will design and implement a food safety and preservation measure for the production of foods in a fast food restaurant. The problem the students face as food engineers is developing a way to keep prepared foods free from disease by altering the growth rate of bacteria and developing methods that will ensure hygienic conditions for the restaurant and its staff.

Unit Overview:

This unit will require students to develop an understanding of the dangers of foodborne illnesses and how food engineers are called upon to develop measures to ensure the safe production, preparation, and preservation of food products. Students will discover how population growth curves predict the spread of bacteria, investigate, compare and design scientific and technological solutions to address personal and societal problems concerning safe food production, and compare the characteristics, structures and life cycles of simple bacterial organisms in order to develop strategies that will ensure foods are safe from bacterial infestations.

Pre Assessment:

Post Assessment:

Credits and References:

Bacteria and Foodborne Illness. Retrieved November 25, 2007, from National Digestive Diseases Information Clearinghouse (NDDIC) Web site: http://digestive.niddk.nih.gov/ddiseases/pubs/bacteria/

Growth of Bacterial Populations. Retrieved November 25, 2007, from Todar's Online Textbook of Bacteriology Web site: http://www.textbookofbacteriology.net/growth.html

Foodborne Illness. Retrieved November 25, 2007, from Centers for Disease Control and Prevention Web site: http://www.cdc.gov/nzbdd/dbmd/diseaseinfo/foodborneinfections_g.htm

Exponential Growth Activity. Retrieved November 25, 2007, from Math Warehouse Web site: http://www.mathwarehouse.com/exponential-growth/exponential-growth-activity.php

Bacterial Growth Curve. Retrieved November 25, 2007, from School of Biological Sciences, University of Leicester Web site: http://www-micro.mbb.le.ac.uk/labwork/Bact/bactb.htm

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Reviews in Time Kits:

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Figure 1. "Just Eat It" TIME Kit
(http://www.thesolutionsite.com/lesson/27203/overview.htm)

In the "Just Eat It " TIME Kit, students will discover how population growth curves predict the spread of bacteria, investigate, compare and design scientific and technological solutions to address personal and societal problems concerning safe food production, and compare the characteristics, structures and life cycles of simple bacterial organisms in order to develop strategies that will ensure foods are safe from bacterial infestations.

3.2 Electric Car "The Fast and The Curious" TIME Kit

Figure 2 shows the overview page of "The Fast and The Curious" TIME Kit. In this TIME Kit, students learn some of the major physics concepts, including electricity, electrical circuitry, and application of Newton's Laws as they design and create an electric powered car.

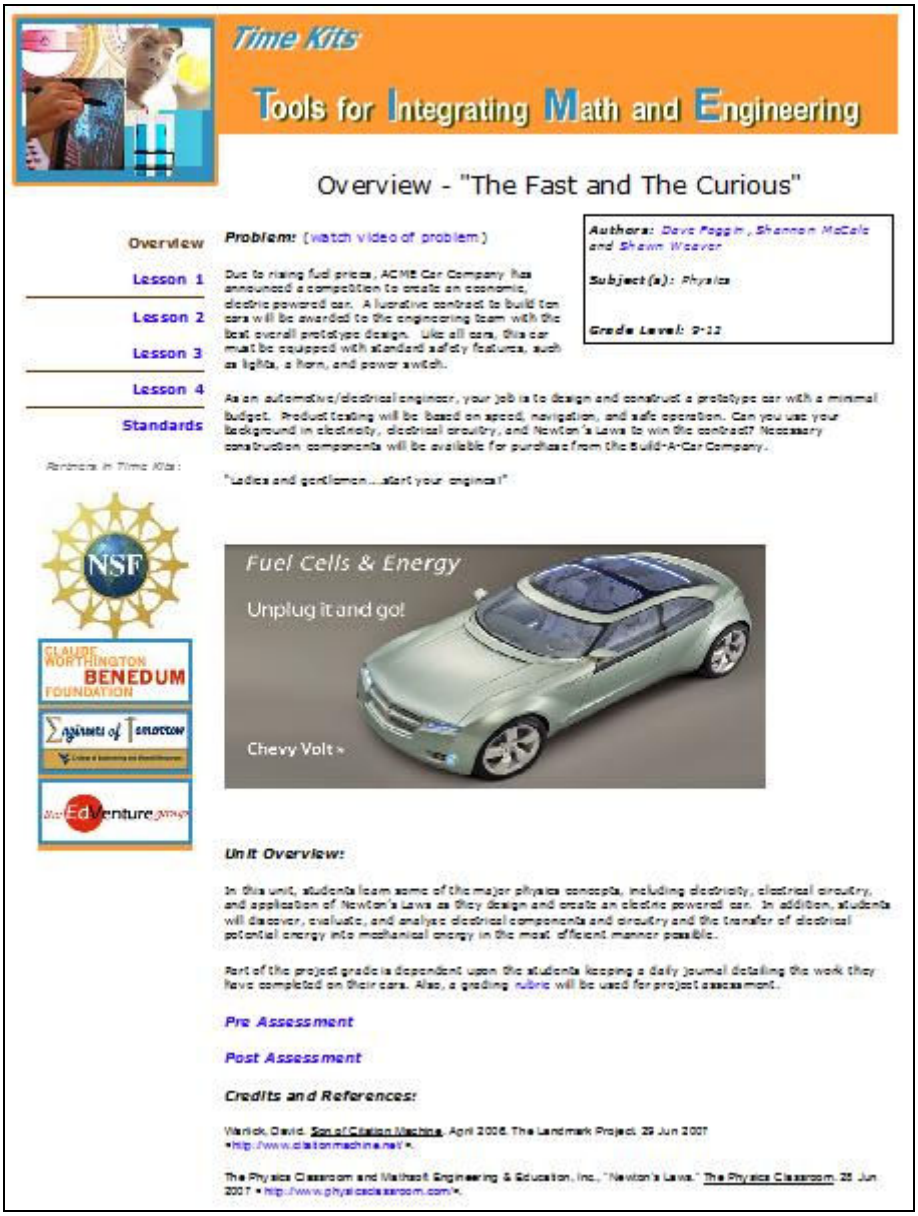


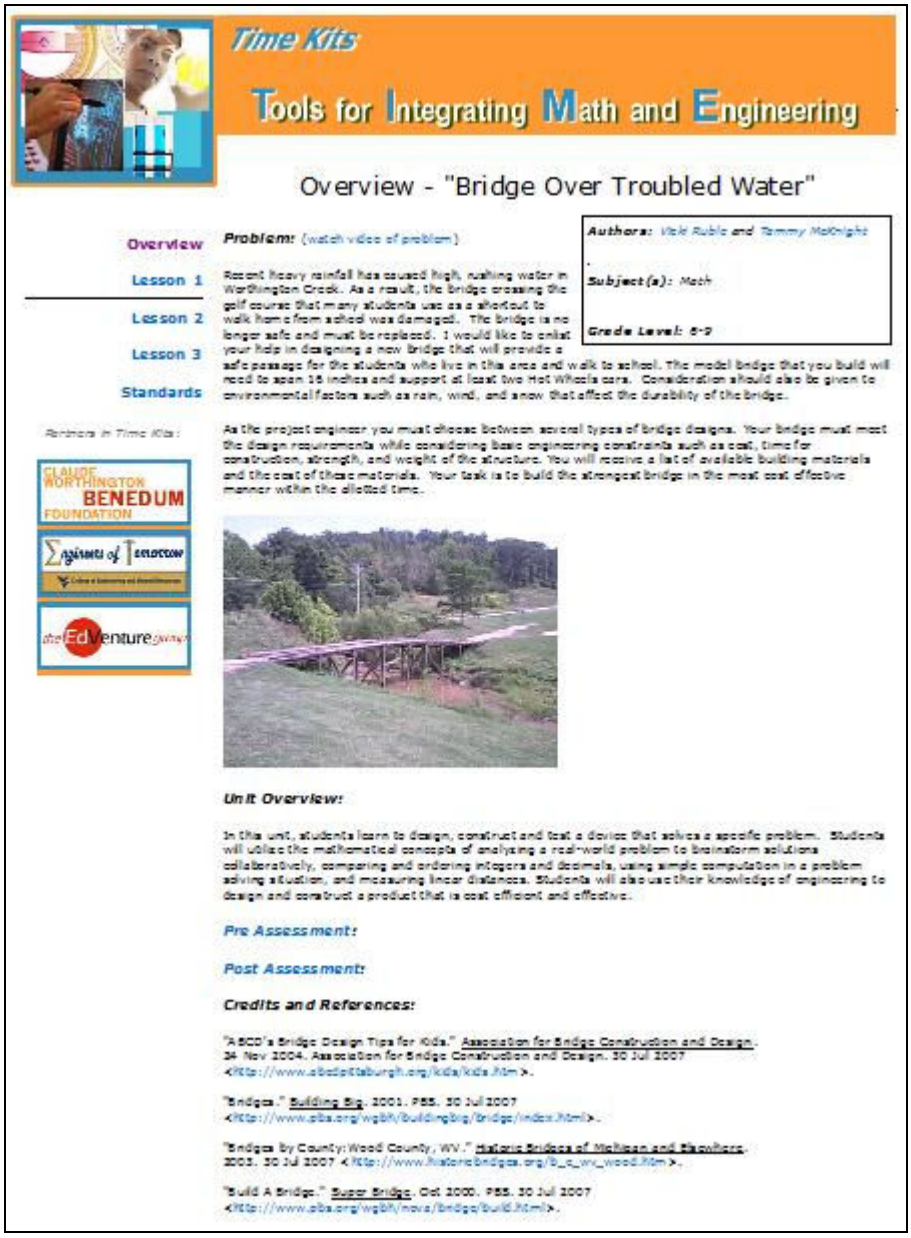
Figure 2. TIME Kit Overview Page
(http://www.thesolutionsite.com/lesson/26803/overview.htm)

In addition, students will discover, evaluate, and analyze electrical components and circuitry and the transfer of electrical potential energy into mechanical energy in the most efficient manner possible. Part of the project grade is dependent upon the students keeping a daily journal

detailing the work they have completed on their cars. Also, a grading rubric will be used for project assessment

3.3 Electric Car "The Fast and The Curious" TIME Kit

Figure 3 shows the overview page of "Bridge Over Troubled Water" TIME Kit. In this unit, students learn to design, construct and test a device that solves a specific problem, a bridge weakened by high, rushing water.



Time Kits

Tools for Integrating Math and Engineering

Overview - "Bridge Over Troubled Water"

Overview
Lesson 1
Lesson 2
Lesson 3
Standards

Authors: Vicki Rubio and Tammy McKnight

Subject(s): Math

Grade Level: 6-9

Problem: (watch video of problem)

Recent heavy rainfall has caused high, rushing water in Worthington Creek. As a result, the bridge crossing the golf course that many students use as a shortcut to walk home from school was damaged. The bridge is no longer safe and must be replaced. I would like to enlist your help in designing a new bridge that will provide a safe passage for the students who live in this area and walk to school. The model bridge that you build will need to span 18 inches and support at least two Hot Wheels cars. Consideration should also be given to environmental factors such as rain, wind, and snow that affect the durability of the bridge.

As the project engineer you must choose between several types of bridge designs. Your bridge must meet the design requirements while considering basic engineering constraints such as cost, time for construction, strength, and weight of the structure. You will receive a list of available building materials and the cost of these materials. Your task is to build the strongest bridge in the most cost effective manner within the allotted time.

Partners in Time Kits:

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Unit Overview:

In this unit, students learn to design, construct and test a device that solves a specific problem. Students will utilize the mathematical concepts of analyzing a real-world problem to brainstorm solutions collaboratively, comparing and ordering integers and decimals, using simple computation in a problem solving situation, and measuring linear distances. Students will also use their knowledge of engineering to design and construct a product that is cost efficient and effective.

Pre Assessment:

Post Assessment:

Credits and References:

"ASCE's Bridge Design Tips for Kids." Association for Bridge Construction and Design. 24 Nov 2004. Association for Bridge Construction and Design. 30 Jul 2007 <http://www.sbcdpittsburgh.org/kids/kids.htm>.

"Bridges." Building Big. 2001. PBS. 30 Jul 2007 <http://www.pbs.org/wgbh/buildingbig/bridge/index.html>.

"Bridges by County: Wood County, WV." Historic Bridges of Michigan and Elsewhere. 2003. 30 Jul 2007 <http://www.historicbridges.org/b_c_wv_wood.htm>.

"Build A Bridge." Super Bridge. Oct 2000. PBS. 30 Jul 2007 <http://www.pbs.org/wgbh/nova/bridge/build.html>.

Figure 3. Sample TIME KIT Overview: Bridge over Troubled Water (http://www.thesolutionsite.com/lesson/27051/overview.html)

To solve the bridge problem, students will utilize the mathematical concepts of analyzing a real-world problem to brainstorm solutions collaboratively, comparing and ordering integers and decimals, using simple computation in a problem solving situation, and measuring linear distances. Students will also use their knowledge of engineering to design and construct a product that is cost efficient and effective.

4.0 Lessons Learned

After completing several years of TIME Kits workshops, we've learned some valuable lessons.

Laptops are better than cash. Getting the best teachers into TIME Kit workshops is not an easy task. Originally we offered a cash stipend of $800 to teachers who participated in the TIME Kits workshop and we had problems recruiting teachers. Last year, we decided to offer a laptop computer ($500 value) and a $300 cash stipend and we ended up with a wait list for the workshop. A portion of the workshop was devoted to teaching the participants how to use their laptops and navigate the new operating system. The participants really seemed to appreciate this aspect of the workshop.

Payment schedule insures follow-through. In the past, we've had teachers attend the five day workshop, receive and cash their $800 stipend check and then fail to respond to communication attempts in order to observe their lesson implementation and collect their pre and post data. In 2007, we implemented a payment schedule in which participants were given a laptop for attendance to the workshop and completed unit, then $300 after the observation of their lesson implementation and collection of their pre and post data.

Units should be tied to the standards. Teachers feel very pressured to only use curriculum directly aligned to their state standards. Often times, lessons that are not aligned to the state standards are frowned upon and only used if there is "extra" time. Having each TIME Kit already aligned to West Virginia's Content Standards and Objectives makes it a "win/win" situation for all WV teachers.

Units should include 21st Century Skills. The Partnership for 21st Century Skills' framework for learning in the 21st century is based on the essential skills that our children need to succeed as citizens and workers in the 21st century. The Partnership has identified six key elements of a 21st century education: Core Subjects, 21st Century Content (Global Awareness, Civic Literacy, Health and Wellness Awareness, etc.), ICT Literacy, Life Skills (Leadership, Ethics, Self Direction, etc.), and 21st Century Assessments (applying skills learned in authentic situations). Ten states have already become P21Leadership states. These states require the use of 21st Century Skills in the classroom – many other states strongly encourage it. Applying 21st Century Skills within each TIME Kit makes them more likely to be picked up and used by classroom teachers.

Unit implementation time should be three days or less. Originally, many of the TIME Kits created were very lengthy, and teachers found that they didn't have two weeks to devote to a

TIME Kit. We began to ask that teachers create units that can be implemented in three days or less. This makes it much easier for a teacher to actually use the TIME Kit in their classroom.

Math and Science teacher teams didn't work. The first TIME Kits workshop required a math and a science teacher team up and write the unit together. This was good in theory, but when implementation time came around, it proved to be very difficult. Math teachers don't have time to teach science standards and vice versa. This made a math teacher-science teacher produced TIME Kit less likely to be used in a classroom, so we ended that practice.

Problem-based learning helps with student engagement. Real life applications are a powerful tool in student engagement. Students seem to really enjoy working in groups to solve an open-ended problem. Student engagement is often half the battle in creating a successful unit. When students are faced with a problem and asked to come up with their own solution, they take ownership of the activity and instantly become more involved with every aspect. Following the problem-based learning model has made TIME Kits much more successful in the classroom.

5.0 Summary

From Congress to industry, there is a continuing need expressed for technically qualified undergraduates, particularly engineers, to address pressing security, economic development and global competitiveness questions for the next generation. While high school students are already heavy users of technology and adapt quickly to wholesale changes, there is a gap in explaining how technologies and applications come to be; once high school teachers understand that engineers simply apply the math and science in real life situations such as improving local air quality or clean energy, they can show students what engineers do using math and science as tools in a real-life engineering application. A STEP project at West Virginia University's College of Engineering and Mineral Resources, Engineers of Tomorrow, works with its partner colleges and private consultant, currently employs a half dozen related interventions to recruit and retain qualified high students interested in engineering with a special emphasis on minority and women engineering students. One of these interventions, the TIME Kit, helps to bridge the divide between engineering as a practice and math/science teachers by providing an integrated curriculum using engineering concepts with web-based delivery. TIME Kits employ mandated 21st Century Skills and NCLB state content standards. Teacher self-reports are extremely favorable; a long term evaluation of short and long-term skill and knowledge change is underway.

Reference

[1] G.L. Winn, D. Lewis, R. Curtis. "Bridging Engineering Education to High School Science Teachers Using TIME Kits." 2009. The International Journal of Engineering Education.

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