Int. J. Engng Ed. Vol. 25, No. 3, pp. 493–498, 2009
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Bridging Engineering Education to High School Science Teachers Using TIME Kits*

GARY L. WINN,[1] DUANE LEWIS,[2] REAGAN CURTIS[3]
[1]*College of Engineering and Mineral Resources,Mineral Resources Building,West Virginia University, Morgantown, WV 26506. USA. E-Mail: Gary.winn@mail.wvu.edu*
[2]*The Edventure Group,63 Wharf Street, Morgantown, WV 26501, USA. E-mail: lmtaylor@edvgroup.org*
[3]*College of Human Resources and Education, Allen Hall, West Virginia University, Morgantown, WV 26506, USA. E-mail: Reagan.curtis@mail.wvu.edu*

The United States clearly needs more technically qualified undergraduates, particularly engineers. Even though high school students are already heavy users of technology, as often are their teachers, there is a gap in understanding how the technologies are derived, developed, prototyped, tested and evaluated. A National Science Foundation STEP project (Science, Technology, Engineering, and Mathematics Talent Expansion Program) at West Virginia University's College of Engineering and Mineral Resources currently employs a carefully crafted intervention, the TIME kit, as an attempt to cross the divide between high school students and math or science teachers by providing an integrated curriculum using real-life engineering problems with web-based delivery. TIME Kits also employ mandated 21st Century Skills and No Child Left Behind state teacher standards to make them more attractive for teachers to use. Statistical treatment of teacher self-reports are favorable and statistically significant on effectiveness of TIME Kits in the field after two years of teacher training; longer term evaluation of student skill and knowledge change is underway. An exemplary TIME Kit that explores the engineering aspects of Acid Mine Drainage is included in our review.

Keywords: Curriculum; design cycle; university partnership; TIME Kit.

INTRODUCTION

IT IS NOW COMMON KNOWLEDGE that the United States is not producing enough STEM (science, technology, engineering, and math) undergraduates to compete in an increasingly global market, to provide sufficient economic opportunity at home, or to sufficiently protect our own borders. In 2005, the National Academies of Science (NAS) presented stirring testimony to the US House of Representatives suggesting that even though the US remains the undisputed leader in many research and development areas, we are not getting young people into the pipeline to engineering and other technology-based careers in adequate numbers. The print version of the testimony, well circulated among academia and elected leaders [1], includes the following excerpt:

> Since the Industrial Revolution, the growth of economies throughout the world has been driven largely by the pursuit of scientific understanding, the application of engineering solutions, and continual technological innovation. 1. Today, much of everyday life in the United States and other industrialized nations, as evidenced in transportation, communication, agriculture, education, health, defense, and jobs, is the product of investments in research and in the education of scientists and engineers. 2. One need only think about how different our daily lives would be without the technological innovations of the last century or so.
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> The products of the scientific, engineering, and health communities are, in fact, easily visible—the work-saving conveniences in our homes; medical help summoned in emergencies; the vast infrastructure of electric power, communication, sanitation, transportation, and safe drinking water we take for granted. 3. To many of us, that universe of products and services defines modern life, freeing most of us from the harsh manual labor, infectious diseases, and threats to life and property that our forebears routinely faced.
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> Although the US economy is fighting hard for survival today, current trends in each of those criteria indicate that the United States may fare even less well in the future without government intervention. This nation must prepare with great urgency to preserve its strategic and economic security. Because other nations have, and probably will continue to have, the competitive advantage of a low wage structure, the United States must compete by optimizing its knowledge-based resources, particularly in science and technology, and by sustaining the most fertile environment for new and revitalized industries and the well-paying jobs they bring. We have already seen that capital, factories, and laboratories readily move wherever they are thought to have the greatest promise of return to investors.
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> *Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (2005) [1].

* Accepted at 30 September 2008.

Issuing a call that led to *Rising Storm*, the US Congress passed the Technology Talent Act authorizing funding for the National Science Foundation (NSF) to provide grants to large and small colleges across the country to increase the number of students receiving associate or baccalaureate degrees in established or emerging fields within the STEM disciplines. These Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP) projects are now solidly in place in over one hundred US colleges and universities as of early 2009. While no two STEP projects are exactly the same in the recruiting and retaining interventions they employ, they share the same goal of increasing the number of STEM graduates. At West Virginia University (WVU), a STEP project called "Engineers of Tomorrow" began in 2005 to bring more Appalachian students, particularly rural kids, underrepresented minorities and women, to engineering as a career path. This large-scale project integrates the College of Engineering and Mineral resources, the College of Human Resources and Education, the College of Arts and Sciences, and The EdVenture Group, Morgantown, West Virginia based, a private consulting and educational resource development company. Similar collaborative projects have been described in the literature on engineering education [2].

In enhancing the pipeline of STEM graduates, one common concern shared by college and high school administrators is how to sensitize high school teachers in math or science (typically, math, physics, chemistry, and biology) about what engineering is. High school science teachers report they are not clear on what engineers do, what career paths are available to undergrads going into engineering, or how to apply math and science in an engineering context. Teachers report that they are reluctant to discuss engineering applications, for example, in forensic science (biology; chemistry; ballistics), 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. Most of the time, and in casual conversation, we find that teachers are actually much closer to explaining engineering applications than they think; once they build some expertise and confidence they become enthusiastic about doing so. Thus, we needed a bridge.

At WVU, the idea for TIME kits (Tools to Integrate Math and Engineering) was born in 2005 as part of our STEP project to cross the gap between math and science content with engineering applications. The College of Engineering and Mineral Resources uses TIME Kits as but one of several interventions in its 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 taught by peer-models [3, 4] to catch students with difficulties early in the term rather than when it is 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 and be able to explain about some of the people who will use and apply math in their career, particularly, engineers.

The Need For TIME Kits: A Bridge Between Teachers and Engineering

Today's learner has access to more information than any preceding generation. Teens spend more time playing Nintendo's Wii, social networking on My Space, and other interactive games / web applications than they do in high school math classes. The younger teachers often are heavy technology users, too, but teachers tell us they do not understand the development process behind technologies they and their students use. They quickly recognize the need for highly-engineered products such as an occupant-weight sensing passenger seat, for example, without asking how products are designed, prototyped, tested, or distributed. They probably do not know what to ask; they will say they are intimidated by engineering in general.

For Appalachian students, minority kids, and high school girls in particular, the explanation process and intimidation may be even more difficult because often there are few college graduates in the family. Economic prospects often appear better in the short run for kids going directly into local industries (e.g. mining, wood products) so that technical career paths appear less lucrative. But because the long-term economic prospects for many of these Appalachian industries are limited, and because many low-tech job prospects are being outsourced anyway, the real way out of dead-end, or low-paying jobs is through a technical career path, especially engineering. We knew anecdotally that once teachers understood basic engineering processes and the myriad career options open to them, they quickly and eagerly realize they can make a change in their students' lives; they can make a difference in local family's lives. Their students can start their own technology-enhanced business. Their students can make a difference, period. The teachers just need to know how to tell their students about engineering.

Where would we begin to train high school teachers about project-based engineering content and career paths [7]? The expectation is to teach a new age of students (and teachers) who are already heavy technology users and to sensitize teachers about how technology creators work. After about a year of brainstorming and informal focus groups, we knew we needed a teaching module to explain engineering as a process and to engage students with specially-crafted curricula addressing societal needs from the students' experience. Thus, the TIME Kit was born.

Just what is a TIME Kit?

The primary thrust of TIME Kits is to create web-based curricula that have a solid foundation in math and science, but immersed in an engineering context. A secondary goal is to meet teacher needs to address curriculum standards mandated by "No Child Left Behind" (NCLB) legislation and the West Virginia Department of Education's emphasis on "21st Century Skills." According to their website, "The Partnership for 21st Century Skills is the leading advocacy organization focused on infusing 21st century skills such as communication and economics, among others into education. The organization brings together the business community, education leaders and policymakers to define a powerful vision for 21st century education to ensure every child's success as citizens and workers in the 21st century." Other skills include problem solving skills; interpersonal and collaborative skills; global awareness; financial and civic literacy (for additional background, see the Partnership website [5]).

The use of TIME Kits is not compulsory for teachers; however, the teachers that do use them will be able to meet required state teachers standards because every TIME Kit addresses one or more such standards. If teachers are at a loss how to present material incorporating another required standard from mandated 21st Century Skills and NCLB state content standards, the TIME Kits are designed to do double duty: present engineering content *and* address teacher standards. Thus, there is an incentive for teachers to use TIME Kits even though they don't have to.

Each TIME kit unit is developed by a certified math or science teacher in a summer development workshop. This intense, five-day workshop exposes teachers to practicing engineers, to engineering career paths, and to technology tools needed to post the final Kit, and reinforces 21st Century skills. Each teacher develops and tests a web-based unit that is ultimately posted to www.thesolutionsite.com [6] for teachers everywhere to use (State teacher standards are translated into other state standards to heighten usage). There are three stages to the development and implementation of the TIME Kits: the summer workshop, unit instruction, and research study.

Stage 1: 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 free-wheeling discussion engages teachers in a process that explains to high school teachers what engineers do and how they do it. The session moderators also discuss the need for students to have a solid technology base for better jobs, but also 21st Century Skills necessary for success in the workplace.

Each TIME Kit addresses the age-old student question of, "When will I ever use this?" at the onset. And so, immediately after the opening discussions, participants begin working directly with industry engineers to align the content they are teaching to real engineering problems. The idea is to bring the technical content to life within the classroom. On top of talking about real-life engineering designs that can easily be drawn from the daily newspaper, throughout the week teachers are exposed to internet resources, technology tools, and new teaching strategies to help develop a unit that engages all students by showing them that engineers solve everyday problems in people's lives.

Each unit is put through an evaluation process that has three levels. Level One is a peer-to-peer evaluation with another teacher in the workshop. The Level Two evaluation is by both an engineering professor and a web development expert. This important evaluation allows an engineering professor to verify connections between the teacher's content and engineering content. The web development expert reviews units to verify that each unit has a solid foundation electronically, that is, they verify that all links, pictures and support documents work correctly. Level Three evaluation is by a curriculum expert who evaluates the unit from a pedagogical perspective. Upon approval at all three levels, each unit is posted to www.thesolutionsite.com for teachers to access.

Lite Flight Gliders is a TIME Kit emphasizing grade 10–12 algebra that was developed during the 2007 summer workshop. This unit engages students in a design competition for a hypothetical government contract to develop a lightweight glider for security or spy purposes—applications students find intrinsically motivating. In essence, students work in collaborative teams to research and develop a paper airplane that is low in cost and flies the farthest. This TIME Kit stresses particular algebraic concepts such as slope as a ratio and collecting and interpreting data. Students define and create scale representations, collect data, create and interpret graphs, and present their project using 21st century skills.

Students at this stage of high school understand the scientific method, and so it is simple to extend those concepts to the engineering design cycle, the same as they would in a freshman engineering class. The student will state the problem, examine alternatives, develop a hypothesis, design, build and refine their prototype glider based on that hypothesis, test their model, compare results with their hypothesis, draw conclusions, and communicate their results. Students are given constraints and specifications to work within; length, width, and weight of the airplane. Throughout the unit students discuss different types of engineers who might work on this project (an aerospace engineer; a mechanical engineer; a chemical engineer; a computer engineer, among others).

Midway, students launch their prototype gliders off a six foot ladder to gather data and then redesign the glider if necessary. Students have a competition at the end of the unit to see which glider flies the farthest and to determine the winner of the contract. In order to meet mandated content standards in WV schools, this unit has incorporated the ratio concept of slope of a line. Students gather data from test flights to calculate slope. Students then use the Pythagorean Theorem, another mandated content standard, to determine how slope is used in a real world context with angle of elevation on airplane take-offs and landings.

Stage 2: Unit implementation

Each teacher is responsible for implementing the unit in the classroom. Teachers 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 are used to make modifications to the units for future use and planning for new workshops.

A page from www.thesolutionsite.com (see Figure 1 below) shows what a math or science teacher would see if they selected "Acid Mine Drainage" as a Time Kit, one of the exemplary Kits that have been prepared so far; it includes coverage of math, chemistry, environmental science and biology concepts wrapped in a real-life engineering design issue: what to do about abandoned mines in Appalachia that leak extremely low Ph water into creeks and streams. Teachers standards which are covered in the Kit are listed on the left side ("Standards"). These pre-made teaching packages, the TIME Kits, bridge the gap between teachers interested in engineering and real life engineering applications.

Stage 3: Ongoing research study

Our goal for the 2009 workshop is to conduct a full field evaluation of every TIME Kit developed (approximately 25 additional units). To this end, 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 attitudes changes differ among students who receive TIME Kit instruction compared to those who receive instruction typical at each school. Treating each unit evaluation (pre/post comparison group design) as a single study and using a meta-analytic approach will allow us to determine whether TIME Kit instruction has consistent significant benefits across a wide range of schools, teachers, and content (units).

TIME Kit results to date with 'lessons learned'

We have trained over 60 teachers who have developed almost 40 TIME Kits for use in the classroom. These teachers have delivered these units to almost 1,000 students in West Virginia schools; at this stage, we have somewhat exceeded our own projections.

More important, we have learned several lessons that are keys to the improvement to the TIME Kits program. In the first year we paired a science and math teacher together to develop a unit that they could teach collaboratively in the classroom. Teachers had difficulty delivering these units for several reasons. Math and science teachers do not have the same students throughout a typical school day. As a result, students were missing some components of lessons when they had different math or science teachers. In year two we separated the math and science teachers so that they could create a subject-specific unit that all math or science teachers could use. Other teachers found that they had been reassigned and wouldn't be teaching the course for which they had developed a TIME Kit.

Another difficulty we encountered in year one was accountability for developing and *evaluating* the units. Teachers were paid a stipend for attending the workshop and developing a unit. In year one we paid the teachers for attending the workshop and developing a unit based on our specifications. Each teacher signed a contract for the completion of the workshop and unit, but the contract was not specific when it came to implementing and collecting data from the units, and many teachers simply did not follow up. In year two the contract was very specific about those completion requirements. We paid each teacher based on completion of a specific task. The results were units of a higher quality and data from the students to support achievement. We will continue with the current contract structure for year three. Finally, we learned that it is important for teachers to have adequate time to work with engineers when developing the units; an hour or two is simply not enough, but two hours on two different days probably is. We will continue to follow that scheme into year three.

Empirical results to date are positive. After attending the TIME Kit workshops, teachers indicated significantly higher engineering content knowledge [$t(22) = 5.9$, $p < 0.05$], and significantly higher agreement that talented students should be encouraged to consider careers in engineering [$t(22) = 2.47$, $p < 0.05$]. In terms of impact on high school students, pre/post assessment data from one of the lessons demonstrated average achievement gains of more than 25%. While not all units demonstrate comparable gains and we do not yet have comparison data, evaluation of student achievement in response to TIME Kit lessons is helping us fine tune each unit and associated evaluation instruments.

Finally, anecdotal teacher reports are consistent and extremely positive. For example, one math teacher said about her TIME Kit experience:

> I think the engineering process is essential to any use in any math/science classroom. I say this because it is just as much of a thinking process as it is a solution process. I find that my students can often times understand how to do certain problems because they remember the algorithmic process needed to get the answer, but they lack a thorough understanding of

Fig. 1. A Sample TIME Kit web page on acid mine drainage. Source: thesolutionsite.com [6]

problem or situation. Many students are good at following step-by-step instructions, but ask them to think about or explain how they got their answer and they are clueless. I think people get intimidated sometimes by the word "engineering." It really is just a word that means "problem solving," though.

Math teacher and TIME Kit developer, 2006

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 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. After three years, teachers say to us that they are more likely to use them in delivery of content than a stand-alone module without context or application. Teacher self-reports are extremely favorable; a long term evaluation of short-term attitude and knowledge change is underway.

Acknowledgement—This material is based upon work supported by the National Science Foundation under Grant No. 0525484. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Support for this project has been gratefully accepted from the National Science Foundation, the Claude Worthington Benedum Foundation, American Electric Power, Peabody Energy, PPG Industries, and NASA. WVU Engineering graduate students Ashley Ashby and Braxton Lewis have made important contributions to this paper.

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Gary L. Winn, Professor in Industrial and Management Systems Engineering, is Principal Investigator on the NSF project, "Engineers of Tomorrow", a multi-dimensional project in the College of Engineering and Mineral Resources designed to increase the number of engineering undergraduates. He teaches Honors Freshman Problem Solving, and also has operated the College's summer engineering camp since 2004. His other research and teaching areas are construction compliance and safety management.

Duane Lewis, former Education Program Manager for the EdVenture Group, earned his BS in Education with a Certification in Mathematics from the California University of Pennsylvania. For the past ten years, he has served as a technology specialist and teacher as he compiled extensive experience in both instruction and assessment to improve student performance. He facilitated the summer and school year workshops for TIME Kits between 2005 and 2008 and assisted in program development and managed the process of unit development and posting to Thesolutionsite.com.

Reagan Curtis is an Associate Professor of Educational Psychology in the College of Human Resources and Education's Department of Technology, Learning and Culture at West Virginia University. A research and evaluation methodologist, his research agenda is diverse including online course development and pedagogy, early cognitive development in mathematics, and post-secondary STEM education among other areas.