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Articles

Bits and Pieces

A New Beginning

As we begin a new school year I usually stop to reflect on the past, what worked and what didn't. This fall is no different, I look forward to new students, new material that I want to introduce them to and the feeling of starting over anew. As I was preparing this volume of JSTE (48-2) and reading over the five manuscripts I realized that starting off a new school year was no different than getting a new volume ready for JSTE. The manuscripts that are included in this issue make me feel that we are starting a new year in JSTE, with new material and new ideas. In addition there are some new authors and subjects in Science, Technology, Engineering, and Mathematics (STEM) that makes learning and teaching enjoyable.

In This Issue

Leading off volume 48-2 of JSTE, Paul Asunda tells us in his manuscript *Open Courseware and STEM Initiatives in Career and Technical Education,* that Science, Technology, Mathematics, and Engineering (STEM) education is a very integral part of Career and Technical Education (CTE). To be successful in today's economies STEM education must stay current with scientific technological innovations that impact curriculums that support STEM education. The author does an excellent job of providing open course software that supports different aspects of enriching STEM activities in CTE curricular subjects.

Following this is another interesting manuscript titled, *Going Virtual: Delivering Nanotechnology Safety Education* *on the Web.* This manuscript by Dominick Fazarro, Heshium Lawrence, and Rochell McWhorter looks at STEM education in a very interesting way. The research deals with nanotechnology and its implications for engaging higher education students in the STEM area. In this manuscript the authors talk about the development of Engineered Nano Materials (ENM) and the impact on today's society. The authors stress the need for safety for those working ENMs. They also identify the need for educators to find creative and innovative ways to educate Generation "Y" students in order to develop a competent workforce.

The next three manuscripts deal with the "E" in STEM, (Engineering). The first of the three was a study conducted by David Stricker titled, *A Case Study: Teaching Engineering Concepts in Science.* The study conducted by the author dealt with an innovative high school engineering curriculum designed to discover changes and constraints to increase math and science literacy. To gather data for the research the author observed students, along with curriculum documents, teacher lesson plans, and teacher resources. The results showed a clear emphasis on creative thought and work and a feeling that students tended to be at ease with this style of pedagogy.

Nathan Mentzer continues this Engineering research with his manuscript titled *High School Engineering and Technology Education Integration through Design Challenges.* The author's research was conducted to identify evidence of students' thinking processes through a naturalistic inquiry on the engineering design process. The research question developed by the author dealt with the engineering design process integrated into a high school technology education context. Results indicated that projects developed in the fall semester provided students with experience and skills in areas of engineering design and material fabrication providing them with the foundation needed for the spring semester.

George Rogers, Todd Kelley, and Gary Werner close out Volume 48-2 of JSTE with a manuscript titled *Perceptions of Indiana Parents Related to Project Lead the Way.* This study was conducted to better understand the perception of parents who had students in Project Lead The Way (PLTW) classes in one Indiana high school. Data was collected and graded on a 5 point Likert scale to best provide the authors with information on how the parents perceived PLTW classes their children were enrolled in. Findings showed that higher level income families viewed PLTW classes more favorably than lower income families and as a result were more inclined to have their children pursue engineering courses in college.

As we begin a new school year we are looking for new material for our classes, I would suggest some very good reading; all the manuscripts in this volume of JSTE might provide you with some very interesting material for this coming year.

Open Courseware and STEM Initiatives in Career and Technical Education

Paul A. Asunda, Ph.D
Southern Illinois University

Abstract

The past several decades have been times of widespread change in world economies. The 21st century has witnessed scientific technological innovations that have had an impact on almost every sector of our social institutions and the way we do things. To succeed in these changing economies and secure meaningful employment, STEM literacy and education is viewed as a priority. This essay reviews STEM initiatives and curriculums that support integration of Science, Technology, Mathematics and Engineering in Career and Technical Education (CTE) curriculum. A variety of open course software that can be directed to address different aspects of enriching STEM activities in CTE curricular subjects is presented.

Paul Asunda is an Assistant Professor in the Department of Workforce Education and Development at Southern Illinois University at Carbondale. He can be reached at pasun07@siu.edu.

Introduction

STEM education is becoming increasingly important given the economic and social issues facing the 21st century workplace. The fields of science, technology, engineering and mathematics (STEM) are viewed by many as critical for the future of any nation and the world as a whole (Lawrenz, Huffman & Thomas, 2006). To compete in the present and future global economy, it is essential for any nation to develop a workforce that is literate and savvy in these areas. It is important for all students to be STEM literate, including those who have not traditionally been able to participate in STEM field and initiatives, to have opportunities to learn the knowledge and skills they will need in a technologically oriented future. The National Governors Association [NGA] (2007) reported that Leon Lederman, a renowned physicist posited that STEM literacy implied that an individual operating in a knowledge–based economy has the ability to adapt to and accept changes driven by the new technology, work with others across borders, anticipate the multilevel impacts of their actions, communicate complex ideas effectively to a variety of audiences, and find measured yet creative solutions to problems which are today unimaginable.

STEM education and initiatives have often been called a meta discipline, the creation of a discipline based on the integration of other disciplinary knowledge into a new whole (Lantz, Jr. 2009). The scope and versatile nature of the Career and Technical Education discipline areas provide a platform for the integration of STEM subject areas, accomplishing the goal of providing all students a STEM geared curriculum. Of late, educators in the field of Career and Technical Education are aligning the curriculum with STEM initiatives. Such a curriculum allows for both a general education perspective and a career and technical education application that prepares students for jobs in the new economy (Addair, 2010; Association for Career and Technical Education [ACTE] 2009; Hyslop, 2010).

The purpose of this essay is therefore two fold, first to examine initiatives that seek to support integration of science, technology, engineering and mathematics in career and technical education constituent subjects; and second to present a list of Open software that can help educators interested in integrating aspects of STEM fields meet the demands of teaching the 21st century students.

STEM initiatives started as a way to promote collaborative practices in STEM education and related curricular areas so that students would be prepared to study STEM fields in college and pursue STEM related careers. President John F. Kennedy's *'Decision to Go to the Moon'* speech almost fifty years ago on May 25, 1961, was a turning point for science, technology, math, and engineering initiatives in the school curriculum. During this period, President Kennedy launched the Apollo program for the space race, challenging NASA's scientists to accomplish the seemingly impossible goal of a manned-moon landing within 10 years. This led to an era of unprecedented scientific research and development that incorporated STEM education initiatives in schools and colleges across the United States, producing a highly trained generation of scientists and engineers, and ultimately making history when Neil Armstrong walked on the moon on July 20, 1969 (Science & Math Informal Learning Experiences [SMILE], n.d.).

The need for public understanding and preparation of future innovators is critical again today. Armario (2011) reported that scores from the 2009 National Assessment of Education Progress released on January 25, 2011 indicated that US students were still struggling in science with less than half considered proficient and just a tiny fraction showing the advanced skills that could lead to careers in science and technology. Further, Armario stated that the secretary of education Arne Duncan said that students are not learning at a rate that will maintain the United States' role as an international innovation leader. In the new global workplace, the long-term economic prosperity and international competitiveness of the United States depends on the country's capacity to innovate in addition to providing a world-class education to all students. In 2009 President Obama identified three overarching priorities to reinvigorate innovation through STEM education initiatives (a) increasing STEM literacy so all students can think critically in these subject areas, (b) improving the quality of math and science teaching in order for American students to no longer be outperformed by those in other nations, and (c) expanding STEM education and career opportunities for underrepresented groups, including women and minorities (Prabhu, 2009).

To this end, the Obama administration launched the *Educate to Innovate* campaign that seeks to harness public-private partnerships to improve STEM education; make STEM education more accessible, move American students up the international rankings in STEM literacy, and expand STEM career opportunities. In his State of the Union Address 2011 the president pledged to prepare an additional 100,000 STEM teachers by the end of the decade (National Economic Council, Council of Economic Advisers, & Office of Science and Technology Policy, 2011).

STEM education offers students one of the best opportunities to make sense of the world holistically, rather than in bits and pieces as they prepare for jobs in the new economy. STEM education removes the traditional barriers erected between the four disciplines by integrating them into one cohesive teaching and learning paradigm helping students make connections between school, community, work, and the global world (Lantz, Jr., 2009). Thus, STEM education is a priority not only because we need today's students to become tomorrow's leaders in innovation and help the US economy, but also to increase STEM interest and skill.

Career and Technical Education (CTE) curricular options play a critical role in preparing individuals for the world of work. CTE offers a holistic education that is dynamic, flexible, and responsive to the ever-changing needs and advances of technology, education, the workforce, and the economy. CTE incorporates innovative methods, ideas, and resources that provide students with a range of skills necessary to be considered workforce ready and secure meaningful work (Bray, Luzzo, Green, Gore, Katt, & Harrington, 2008).

One curricular option that has gained momentum within the field of CTE is the linking of technology education programs with engineering preparation programs. The field of technology education has edged closer to infusing aspects of engineering design into the curriculum. To further complement these efforts, professional bodies and organizations that are affiliated to CTE and workforce preparation have renamed themselves and retooled their missions and goals. Consider the following trends:

1. The formation of the National Center for Engineering and Technology Education (NCETE) in 2005. The ultimate goal of NCETE is to rethink the pedagogy of technology education programs to include more engineering content and design, problem solving, and analytical skills and to implement those changes in technology teacher education programs around the United States.
2. The renaming of International Technology and Engineering Educators Association (ITEEA) formerly known as International Technology Educators Association (ITEA). ITEEA is devoted to improving

technology education and engineering through the use of technology, innovation, design, and engineering experiences at the K-12 school levels,

3. Renaming of the technology education division of the Association of Career and Technology Education to Engineering and Technology Education Division, with a lower case “e” i.e. eTED as its acronym.
4. The National Association of Industrial Technology changed its name two years ago to the Association of Technology, Management and Applied Engineering (ATMAE) and, most recently the National Association of Industrial and Technical Teacher Educators (NAITTE) is now the Association for STEM Teacher Education (ASTEM).

Such endeavors continue to provide a framework for the integration of science, technology, engineering and mathematics into the CTE curriculum. Further, Herschbach (2009) noted that in contemporary school curriculums at all instructional levels and particularly at the middle and high school levels, the term engineering has found its way into course descriptions in one form or another. According to Gattie and Wicklein (2007), an engineering perspective emphasis provides a vehicle to, (a) increase interest and improve competence in mathematics and science among CTE students by providing an arena for synthesizing mathematics and science principles and (b) improve technological literacy by exposing students to a more comprehensive methodology that generates the technology.

Technology Education, STEM Related Curriculums, Initiatives, and Organizations

The notion that technology education boosts technological STEM literacy may encourage students to pursue more studies in science, mathematics, and engineering. In recent years, academies, online curricular activities, and organizations that engage in STEM education have been established to encourage the infusion of STEM not only in technology education but in all subjects purported to be related to engineering education. For example, Schaffhauser (2011) reported that Purdue University had introduced an online course developed for elementary teachers specifically to strengthen their teaching strategies in STEM. In this essay, efforts to integrate STEM into the school curriculum will be viewed to comprise (a) STEM related curriculums, and (b) STEM related initiatives and organizations.

STEM Related Curriculums

Examples of pre-engineering curriculums that embrace STEM outreach activities that seek to integrate technology education aspects include: Project Lead the Way, STEM Academy, CISCO investment in STEM, and Microsoft Math Partnership. Project Lead the Way (PLTW) is a national pre-engineering program that partners with middle schools and high schools to provide a rigorous, relevant STEM education. Through an engaging, hands-on curriculum, PLTW encourages the development of problem-solving skills, critical thinking, creative and innovative reasoning. The STEM academy program is designed to improve STEM literacy for ALL K-12 students. It is presented in a Moodle format (an open source course management system) and is accessed via the Web. This program is built around hands-on projects that focus on standards-based foundations, gender awareness, socio-economic concerns, and general learner needs that seek to improve STEM literacy for all students.

Cisco Networking Academy provides comprehensive coursework to teach the “T” in STEM education, i.e. applied computer technology related skills that lead to industry based certifications like Cisco Certified Network Associate (CCNA), and Cisco Certified Network Professional (CCNP) that reinforce skills in technology, math, science, and engineering. Cisco curriculum is offered through online coursework, detailed lesson plans, assessments, and teacher professional development (Cisco Networking Academy, 2010).

The Microsoft Math Partnership (MMP) program is highly concentrated in Washington State. It is a public-private initiative to enable educators, and encourage businesses and the state government to focus new attention and resources on improving middle-school students' participation and achievement in math, science and technology. Over time the plan is to expand MMP programs to other states. In contemporary CTE classes, educators are implementing STEM related curriculum in an effort to integrate STEM initiatives into their instructional activities (Microsoft, 2009).

STEM Related Initiatives and Organizations

Several national organizations that support STEM initiatives include the following:

The National Aeronautics and Space Administration (NASA) has a primary responsibility for advancing America's scientific security and economic interests through robust space exploration and aeronautics research programs. NASA missions to understand and explore depends upon educated, motivated people and as such has a strong interest in inspiring and motivating students to pursue careers in science, technology, engineering and math. NASA, thus implements programs to advance STEM education, for example the NASA Means Business competition. In this competition college students compete to develop promotional plans to encourage educators to involve their students in outreach activities that support STEM education (National Science Foundation and National Aeronautics and Space Administration, 2007).

The National Consortium for specialized Secondary Schools of Mathematics, Science and Technology (NCSSSMST) is the nation's alliance of secondary schools and programs preparing students for success and leadership in science, technology, engineering, and mathematics. It seeks to serve its members' students and professionals, by fostering collaborations, to inform STEM policy, and to advocate transformation in education.

National Math and Science Initiative (NMSI) was formed following a report issued in 2005 by the National Academies entitled "Rising Above the Gathering Storm." This document reported that among America's greatest economic and intellectual threats was the decline in the number of students who are prepared to take rigorous college courses in math and science and equipped for careers in those fields. NMSI supports training and incentive programs for both teachers and students in Advanced Placement and Pre-AP math and science courses. It also supports the expansion of UTeach, a program that encourages math and science majors to enter the teaching profession by offering compact degree plans, early teaching experiences, and financial assistance for undergraduates.

National Action Council for Minorities in Engineering (NACME) provides leadership and support toward increasing the representation of people of color i.e. African American, American Indian, Latino women and men etc. in STEM-focused careers.

National Science Foundation: Advanced Technological Education Program, with an emphasis on two-year colleges, the Advanced Technological Education (ATE) program involves partnerships between academic institutions and employers to promote improvement in the education of science and engineering technicians at the undergraduate and

secondary school levels. The ATE program supports curriculum development; professional development of college faculty and secondary school teachers; career pathways to two-year colleges from secondary schools and from two-year colleges to four-year institutions; and other activities. A secondary goal is articulation between two-year and four-year programs for K-12 prospective teachers that focus on technological education.
American Association for the Advancement of Science (AAAS): Project 2061 is a long-term initiative of AAAS to help all Americans become literate in science, mathematics, and technology. To achieve this goal, Project 2061 conducts research and develops tools and services that educators, researchers, parents and families, and community leaders can use to make improvements in K-12 education and beyond (National High School Alliance [HS Alliance], n.d.).

In addition to the aforementioned national initiatives, different states have implemented programs and organizations to meet STEM needs at the local levels. A common theme that transverse the STEM related curriculums and STEM related initiatives and organizations is that they implement the power of the World Wide Web and computer related technologies to share information and supplement instruction geared toward infusing aspects of STEM into the curriculum.

Teaching STEM in the 21st Century

Twenty-first century educators are constantly bombarded with changes including new methods of communication, new forms of technology, and ever changing teaching practices that seek best ways to instruct and disseminate information. In most recent times, global competition for STEM talent is growing as many countries increase their capacity to improve their own STEM education systems. Addair (2010) indicated that demand for STEM professionals with education past high school but below a bachelor's degree is increasing. Nonetheless, it is worrying that amid the worst economic recession in decades, hundreds of thousands of technology-related jobs went unfilled in 2009 due to a lack of qualified workers. The US Department of Labor has projected that by 2018 the US will have more than a million of job openings in STEM fields, i.e. healthcare workers, veterinary doctor assistants, pharmacy technicians, forensic-science technicians and dental hygienists are some of the fastest growing occupations (Lacey & Wright, 2009). To succeed in economies that are rapidly embracing STEM related careers, individuals would be required to develop the skills necessary to secure meaningful employment. As a consequence this has posed a great challenge to teachers at all levels of the academy to seek ways to be responsive and accommodate in their teaching the changing needs of the workforce and students.

Dugger (2010) argued that there are a number of ways that STEM can be taught in schools today. One way is to teach each of the four stem disciplines individually. Another way is to teach each of the four STEM disciplines with more emphasis going to one or two of the four; this is what is happening in most US schools today. A third way is to integrate one of the STEM disciplines into the other three, e.g. integrating engineering aspects into science, technology and mathematics. And lastly, a more comprehensive way is to infuse all four disciplines into each other and teach them as an integrated subject matter. It is imperative that teachers become STEM technically literate as well as be aware of various STEM teaching models, in addition to available open source and freeware software that may supplement their teaching.

Open Source Software and STEM Instruction

A 2010 report to the president of the United States; "*Prepare and Aspire: K12 education in Science, technology, engineering and Math (STEM) for America's Future*" documented that educational technology can power innovative learning tools and traditional teaching methods that could dramatically improve STEM preparation and inspiration of all students, including those at risk of losing interest in STEM subjects (President's Council of Advisors on Science and Technology, 2010). Similarly, a national research report on teachers' media usage found that educators are incorporating more internet dependent technologies into their instruction. The report also revealed that shrinking school budgets were promoting many educators to look for free resources (Devaney, 2011).

The advancement of educational technology and availability of open course software has enhanced teaching, impacting the way educators instruct at all levels of education. Open source software is computer software that has a source code available to the general public for use as is or with modifications. "Open source software" is also called "Free software", "libre software", "Free/open source software (FOSS or F/OSS)", and "Free/Libre/Open Source Software (FLOSS)" (Couros, 2006). Open-source software gives educators more options than ever before. Today, instructors have dozens, if not hundreds, of options for free and open source applications that help them present lessons on everything from learning the alphabet to complex algebra computations. Open source software can be developed to support customization, such as instructional materials that include different approaches suited to different levels, learning styles, and problem sets that may adapt to student responses.

Open source software can provide simulations and engaging visual lessons as well as projects that can help students comprehend why they need to learn certain key concepts that may enhance STEM literacy. Software that supports STEM concepts helps students understand how the “S”, “T”, “E” and “M” work in tandem. Science deals with and seeks the understanding of the natural world (National Research Council [NRC], 1996). Thus the science component in STEM promotes scientific literacy which is the ability to use scientific knowledge i.e. physics, chemistry, biological sciences, and earth/space sciences to understand the natural world and participate in decisions that affect it (NGA, 2007). The technology piece allows for a deeper understanding of the three other components of STEM education. ITEA (2007) stated technology is the modification of the natural world to meet human needs and wants. On the same note, Dugger (2010) stated that technology is concerned with what can and should be designed, made and developed from natural world materials and substances to satisfy human needs and wants. Some processes used in technology to alter and change the natural world are “invention”, “innovation”, “practical problem solving” and “design”. Thus the “T” perpetuates technological literacy, which implies the ability to use, manage, understand and access technology. Technological knowhow and skills allows students to apply what they have learned, utilizing computers with specialized and professional applications like CAD, CAM, and computer simulations and animations to design artifacts that satisfy human needs. The engineering aspect of STEM education puts emphasis on the process and design of solutions, instead of the solutions themselves. Engineering literacy is the understanding of how technologies are developed via the engineering design process. Engineering design is the systematic and creative application of scientific and mathematical principles to practical ends such as design, manufacture, and operation of efficient and economical structure, machines, processes and systems. This approach allows students to explore mathematics and science in a more personalized context while helping them to develop the critical thinking skills that can be applied to all facets of their work and academic lives as they understand the build world around (NGA, 2007). Dugger (2010) stated that the mathematics component provides an exact language for technology, science, and engineering. Hence, mathematical literacy means the ability of students to analyze reason and communicate ideas effectively as they pose, formulate, solve and interpret solutions to mathematical problems in a variety of situations (NGA, 2007).

STEM literacy does not imply achieving literacy in these four areas distinctively, but calls for designing STEM instruction to help students articulate how the four disciplines weave together to realize solutions to practical problems and challenges. Open source software and simulations can help meet this goal. Open source can be used to supplement learning that embraces STEM aspects, allowing students to explore CTE curricular options in greater detail and in practical application (Lantz, Jr., 2009). If appropriately used, open source software can provide varied teaching strategies experiences like online instruction, project based assignments, videos, webgames, lab and job simulation, and social networking communities. These strategies help educators provide students with learning opportunities that exemplify real world content and hands on lab opportunities that may increase students engagement in STEM related content, as well as help them comprehend how the disciplines work together. Additionally open source software might provide teachers with ongoing opportunities for professional development training. This allows for collaboration, creating a community of peers among those interested in STEM instruction.

Constructivism Theory, STEM and Open Source software in CTE Instruction

Recent theories focusing on the nature of learning promote the constructivism theory. Schunk (2004) explained that constructivism is not a theory but an epistemology that explains the nature of learning and how individuals construct what they learn and understand. Thus, a number of educators have come to regard constructivism as a learning theory. Knowles, Holton, and Swanson (1998) argued that constructivism stressed that all knowledge is context based and that individuals make personal meaning of their learning experiences. It then follows constructivism as a learning approach augurs well with contextual learning as described by Brown (1998). Brown stated that Contextual teaching and learning theory is rooted in constructivist practice. Teaching in a context is not a new idea; in his writings Jean Piaget (1968) viewed the origin of knowledge as genetic epistemology which he also called constructivism, due to his belief that knowledge acquisition is a process of continuous self-construction. Further, John Dewey (1963) stated that there was an intimate and necessary relation between the process of experience and education. According to Dewey this was a fundamental aspect toward application of contextual learning into U.S. classrooms. Dewey advocated a curriculum and teaching method tied to children's experiences and interests. Such experiences promote authentic learning experiences helping the teacher to connect topical content to real world situations and stimulate students to make their own connections between knowledge and its applications to their lives. One good example of teaching in a contextual environment as viewed by Piaget (1968) and described by Dewey (1963) is the *West Bridge Design Contest*, a simulator software designed to offer students realistic, engaging introduction to engineering concepts. In this simulator contest students learn about the engineering design process by applying math, science, and technology to create devices and systems that meet human needs. Such a group-wide inquiry project poses a problem to students, requiring them to conduct original research where they must use technology to gather and analyze data, design, test, and improve upon a proposed bridge design that is perceived as a viable solution. In light of this, it can be argued that the activity in which knowledge is developed and deployed is not separable from learning and cognition (Brown, Collins & Duguid 1989). In other words, learning and cognition may be fundamentally situated in an activity. This affords students with a problem solving learning opportunity that is realistic and hands on.

Various open source software programs on the World Wide Web can be integrated into the curriculum to teach STEM concepts providing students with opportunities to be innovative in a contextual learning environment. Open source software that supports such an initiative provides students opportunities of cognitive apprenticeship as described by Brown, et al. (1989). Cognitive apprenticeship methods try to enculturate students into authentic practices through activity and social interaction that may support innovation. Such learning experiences help students engage in virtually the same types of problem solving activities that real innovators do but perhaps not on the same scale. Brown, et al. further postulated that activity shapes students' skills and provides experiences that are important in understanding concepts. They stated that representations arising out of activity cannot easily be replaced by descriptions. Greeno, Moore and Smith (1993) stated that, for students to make connections between concepts, instruction should be designed to influence the activity so that it includes attention to affordances that are invariant across changes in the situation and that will support successful interactions in a new environment.

In view of these observations, open source software when appropriately incorporated into STEM education can fit into any of the STEM instructional models as described by Dugger (2010). Such an undertaking can provide students with hands-on activities and virtual innovative field trips that are meaningful and relevant to students' lives and the world around them. Such opportunities might be said to enhance STEM literacy as well as co-produce innovative knowledge through activity and collaborative learning. Thus, contemporary learning theories provide instructors with strategies to incorporate open source software that afford learners with a variety of learning opportunities that enhance STEM instruction. However, to be able to utilize open source software to their fullest potential as teaching tools, educators need to understand the fundamental difference between open source and freeware software and their limitation.

Open Source Software for STEM Instruction in CTE

Open source software typically does not require a license fee. Alternatives to open source software are *freeware, free software, and shareware*. Freeware is software that is made available for everyone to use at no cost e.g. web browsers like Mozilla Firefox however, the author retains the copyright and users cannot modify the source code unless they get permission to do so. On the other hand, free software is software that can be used, modified, copied and redistributed without restriction and for no cost, e.g. Moodle course management system. A major difference between free software and freeware is that freeware is not proprietary and can be distributed freely. Therefore, educators should note that some proprietary software may not be compatible with free software, for example, those that depend on a user paying for a license in order to lawfully use a software product. Lastly, Shareware is a type of software and a way to distribute the software. Authors of shareware give users a license to try out the software for a specific period of time. If a user wishes to continue using the software after this trial period, he or she is required to register with the author by paying a small fee (Ontario ministry of small business and consumer services, 2008).

Use of open source and freeware software may be considered supplemental if educators incorporate them appropriately in their teaching practices enabling students to realize instructional learning objectives in a way that previously could have not been met. Educators need to know that this group of software can help them and the institutions they work for save on licensing costs, maintenance costs because of increased reliability over a period of time, flexibility with regard to modification of software to meet instructional needs, and on training costs for both technical staff that support and use the system. However, free comes with limitations and costs, some of the downsides associated with open source software according to the Ontario ministry of small business and consumer services (2008) include but are not limited to: (a) lack of personalized support, unlike proprietary software, open source and freeware software do not come with phone support or personalized e-mail support, (b) restricted choice, there are fewer program choices available for open source or freeware software, (c) speed of change, every day software is being modified in the open source world, which can make it difficult to ensure that the software is compatible with other applications, and (d) no warranty, open source and freeware software does not come with a warranty, as there is no single company backing the product.

Thus, educators at all levels should consider whether the overall costs of using an open source or free ware software will be higher than that of proprietary software in addition to its relevancy to support desired learning outcomes of the program and courses in which it is used.

Figure 1 and 2 illustrate some freeware and open source software that could be utilized in a technology oriented classroom to facilitate integration of STEM activities and support educators teaching philosophies (PcWorld, 2009). In addition, the following sites provide additional links to resources that teachers and students may find useful:

1. http://www.educational-freeware.com, this site specializes in finding and reviewing high-quality free learning software and Websites from the Internet;
2. http://www.user.shentel.net/rbowman/files/myfree.htm, contains an extensive list of free educational technologies software that technology teachers do not want to miss;
3. http://www.dirfile.com/freeware/teachers.htm, offers a list of freeware for teachers use
4. http://www.bestfreewaredownload.com, this site categorizes free software into those for Audio, Graphics, Web development etc.
5. http://www.filehippo.com, contains several categories of freeware, demo and shareware programs that can be downloaded
6. http://www.oercommons.org, and http://www.curriki.com/ offer free-to-use teaching and learning content like K-12 lessons, college courses etc. from around the world;
7. http://opensource.ebswift.com/, software is classified into categories e.g. system, educational, graphics, webmaster resources, games etc
8. http://en.wikipedia.org/wiki/List_of_open_source_software_packages, the Wikipedia page for open source software packages.

9. http://free.ed.gov/ Federal Resources for Educational Excellence, is a U.S. Department of Education website that compiles free teacher resources with topics from Math to World Studies.
10. http://www.teach-nology.com/ TeAchnology provides free and easy to use resources for teachers dedicated to improving the education of today's generation of students.

Figure 1: Freeware software in Science, Technology, Mathematics, and Engineering subjects

SCIENCE		
Freeware Tool	Description	Site
Genius Maker 3.00 freeware	1-Genius Maker contains 34 educational softwares covering the subjects Mathematics, Physics and Chemistry for High school students. Out of 34 softwares, 9 software's are Free and the remaining are for trial.	http://www.bestfreewaredownload.com/freeware/t-free-genius-maker-freeware-tktjpbgi.html
LDS Home schooling	2-Site is designed for home schooling. Contains links to more than 100 free courses for sciences.	http://ldshomeschoolinginca.org/science.html

TECHNOLOGY		
Freeware Tool	Description	Site
4teachers.org	site helps teachers locate and create ready-to-use Web lessons, quizzes, rubrics and classroom calendars.	http://www.4teachers.org/
easy freeware	Archive of freeware downloads that contains hotlinks to various technology Freeware.	http://www.easyfreeware.com/freeware/technology.html

MATHEMATICS		
Freeware Tool	Description	Site
Math for kids10	Free math lessons and math homework help from basic math to algebra, geometry.	http://www.rocketdownload.com/program/math-for-kids-79194.html
Mixed up math 1.0	A math puzzle where equations are mixed-up.	http://www.rocketdownload.com/program/mixed-up-math-10268.html
Math basics	Math Basics is a simple math quiz application – only available for those with Macintosh computer systems.	http://www.rocketdownload.com/program/math-basics-79193.html

ENGINEERING		
Freeware Tool	Description	Site
Filebuzz	Page presents engineering software with snap shots and descriptions of each software.	http://www.filebuzz.com/files/engineering/freeware-1.html
Uconeer	Uconeer has 397 units in 46 categories. Covers all the basic categories but adds engineering specific categories like enthalpy, entropy, heat capacity, heat transfer coefficient, moment of inertia, stress, surface tension, thermal conductivity, torque and viscosity.	http://www.easyfreeware.com/uconeer-109-freeware.html
Electrical Mechanics	Electrical, Mechanics and Maths engineering educational software package.	http://www.bestfreewaredownload.com/download/t-free-electrical-mechanics-and-maths-freeware-tsletozf.html

2D ENGINEERING		
Freeware Tool	Description	Site
A9CAD	A9CAD is an excellent ACAD-compatible program for the occasional CAD use.	http://www.a9tech.com/
CadStd	CadStd is a general purpose, easy to learn CAD/drafting program.	http://www.apperson.org/cadstd/
JustCad	JustCad is designed, to make cad drawing as simple as possible.	http://www.justcad.com
Blender	Blender is a free open source 3D content creation suite.	http://www.blender.org

3D ENGINEERING		
Freeware Tool	Description	Site
Google SketchUp Pro8	Google SketchUp Pro 8 is a suite of powerful features and applications for design and engineering professionals.	http://www.google.com/sketchup/download/
Vector Engineer Cad Software	A complete technical drawing and multi-purpose cad software system that offers all the features required to create accurate professional drawings.	http://www.vectorengineer.com/

Figure 2: Software for general uses as preferred

SCIENCE		
Freeware Tool	Description	Site
Genius Maker 3.00 freeware	Genius Maker contains 34 educational softwares covering the subjects Mathematics, Physics and Chemistry for High school students. Out of 34 softwares, 9 software's are Free and the remaining are for trial.	http://www.bestfreewaredownload.com/freeware/t-free-genius-maker-freeware-tktjpbgi.html
LDS Home schooling	Site is designed for home schooling. Contains links to more than 100 free courses for sciences.	http://ldshomeschoolinginca.org/science.html

TECHNOLOGY		
Freeware Tool	Description	Site
4teachers.org	site helps teachers locate and create ready-to-use Web lessons, quizzes, rubrics and classroom calendars.	http://www.4teachers.org/
easy freeware	Archive of freeware downloads that contains hotlinks to various technology Freeware.	http://www.easyfreeware.com/freeware/technology.html

MATHEMATICS		
Freeware Tool	Description	Site
Math for kids10	Free math lessons and math homework help from basic math to algebra, geometry.	http://www.rocketdownload.com/program/math-for-kids-79194.html
Mixed up math 1.0	A math puzzle where equations are mixed-up.	http://www.rocketdownload.com/program/mixed-up-math-10268.html
Math basics	Math Basics is a simple math quiz application – only available for those with Macintosh computer systems.	http://www.rocketdownload.com/program/math-basics-79193.html

ENGINEERING		
Freeware Tool	Description	Site
Filebuzz	Page presents engineering software with snap shots and a description of each software.	http://www.filebuzz.com/files/engineering/freeware-1.html
Uconeer	Uconeer has 397 units in 46 categories. Covers all the basic categories but adds engineering specific categories like enthalpy, entropy, heat capacity, heat transfer coefficient, moment of inertia, stress, surface tension, thermal conductivity, torque and viscosity.	http://www.easyfreeware.com/uconeer-109-freeware.html
Electrical Mechanics	Electrical, Mechanics and Maths engineering educational software package.	http://www.bestfreewaredownload.com/download/t-free-electrical-mechanics-and-maths-freeware-tsletozf.html

2D ENGINEERING		
Freeware Tool	Description	Site
A9CAD	A9CAD is an excellent ACAD-compatible program for the occasional CAD use.	http://www.a9tech.com/
CadStd	CadStd is a general purpose, easy to learn CAD/drafting program.	http://www.apperson.org/cadstd/
JustCad	JustCad is designed, to make cad drawing as simple as possible.	http://www.justcad.com
Blender	Blender is a free open source 3D content creation suite.	http://www.blender.org

3D ENGINEERING		
Freeware Tool	Description	Site
Google SketchUp Pro8	Google SketchUp Pro 8 is a suite of powerful features and applications for design and engineering professionals.	http://www.google.com/sketchup/download/
Vector Engineer Cad Software	A complete technical drawing and multi-purpose cad software system that offers all the features required to create accurate professional drawings.	http://www.vectorengineer.com/

Conclusion

In this essay a variety of organizations that support STEM initiatives, STEM curriculums and possible open source software that may support the instruction of science, technology, engineering and mathematics (STEM) have been presented. Employment prospects in contemporary society as well as those of the future will heavily depend on those that are STEM literate. In other words, those with skill sets and knowledge of how the four disciplines and general education weave together to realize solutions to practical problems, and are better prepared to innovate and compete in the global economy will be at an advantage. Technological innovations will constantly change the way that students learn and how teachers plan and disseminate knowledge. Thus the 21st century CTE educator is challenged to seek innovative ways to integrate and supplement their teaching practices with new technologies to prepare students for the world of work in a learning environment with dwindling resources. Availability of open source and freeware software can provide instructors with supplemental teaching resources that can help them connect with 21st students as well meet curriculum objectives. Not only CTE instructors but also all educators will be required to seek and attend professional development activities that will impart and update their knowledge and skills of the potential of these innovative software technologies in supporting learning outcomes, and how students may use them. To this end STEM literacy, availability and appropriate use of open source and freeware software to support desired learning outcomes will be a big component in the professional development of all educators who seek to integrate aspects of STEM education into their instructional practices.

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Going Virtual: Delivering Nanotechnology Safety Education on the Web

Dominick E. Fazarro
Heshium R. Lawrence
Rochell R. McWhorter
The University of Texas at Tyler

Abstract

The emergence of nanotechnology has created new challenges for the 21st century. Future development of Engineered Nano Materials (ENMs) will soon impact society in ways never imagined before. Most importantly, those who develop and work with ENMs must understand the importance of worker safety. Educators must use creative and innovative ways to educate Generation 'Y' to develop a competent nano workforce. We posit that the use of virtual environments in education may be the conduit between Generation 'Y's technology connectedness and the teaching of nanotechnology safety education effectively, and cite an example of teaching nanotechnology safety education in a virtual world. In addition, this method of instruction may have implications for engaging higher education students in the STEM area of nanotechnology.

Dominick E. Fazarro, Ph.D., is an Associate Professor in the Department of Human Resource Development & Technology at The University of Texas at Tyler. He can be reached at dfazarro@uttyler.edu.
Heshium R. Lawrence, Ph.D., is an Assistant Professor in the Department of Human Resource Development & Technology at The University of Texas at Tyler. He can be reached at hlawrence@uttyler.edu.
Rochell R. McWhorter, Ph.D., is an Assistant Professor of Human Resource Development in the Department of Human Resource Development & Technology at The University of Texas at Tyler. She can be reached at rmcwhorter@uttyler.edu

Introduction

The 21st century presents significant challenges in developing innovative materials and products to remain competitive in a global market. Nanotechnology is a burgeoning new field creating new avenues for developing innovative products (Feather & Aznar, 2011). This new area of science and engineering may be considered the "new industrial revolution" and is expected to impact society like never before (Holley, 2009; Uldrich & Newberry, 2003). Further, the Project on Emerging Nanotechnologies (PEN) indicates 1,200 companies, universities, and government laboratories are engaged in nanotechnology research, which is known as the *Nano Metro* (PEN, 2009).

By 2015, there will be approximately two million workers globally in nanotechnology (Roco, 2003). The makeup of the new workforce will consist of researchers, technicians, manufacturing engineers, and production workers (NNI, 2009). For the majority of educators, nanotechnology is still an ambiguous topic. Toon (2006), indicated educators had little or no knowledge about nanotechnology. Fazarro (2011) stressed, "[Educators] must appreciate the role nanotechnology will have on society, understand what is required to prepare the nanotechnology workforce, and successfully 'get the word out' to students and parents" (p. 208).

Purpose of this Article

The purpose of this article is three-fold: 1) to inform educators in the field about nanotechnology, 2) to build the case for nanotechnology safety education to prepare the workforce for this emerging industry, and 3) to provide a conceptual framework to design and implement nanotechnology safety education in a virtual environment. Each of these three purposes will be described next.

Nanotechnology: The New Frontier

Nanotechnology ("nano") describes structures of 100 nanometers or smaller (Lin & Allhoff, 2007) and has been defined as "the technology of structuring and controlling matter on the scale of ~100nm and below" (Van Nedervelde, 2006, p. 6); an accelerated rate of development of new and innovative products incorporating nanoparticles is occurring. According to Lawrence (2010), nanotechnology incorporates technology "to make available a fundamental understanding of observable fact and materials at the nanoscale and to build and use structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size" (p. 159). Companies like Proctor & Gamble, LG Electronics, and Siemens are researching structures beginning at the 100 nanometer (nm) boundary (Lin & Allhoff, 2007; NanotechCompanies.us, 2010). To attempt to visualize how small *nano* is, consider the width of a human hair, which is 100 micrometers, and about 50,000, to 100,000 nanometers in diameter; to illustrate with another example, a sheet of copy paper is about 100,000 nanometers in thickness (See Introduction to Nanotechnology, 2007; University of Wisconsin-Madison, 2008; Wikipedia, 2011). For some, it may seem like science fiction, but it is reality and educators should inform others. See Figure 1 for image of nanorice (nanometer) structure.

Figure 1. Images of Nanorice

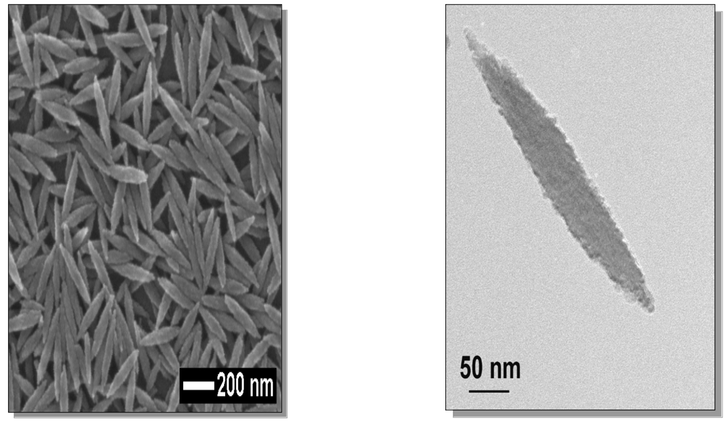


Figure 1. Image on the left is nanorice composed of non-conducting iron oxide-hematite covered with gold. Image on the right is a magnified nanorice . Used with permission from the Office of Media Relations, Rice University © 2006. Used with permission.

Actually, nanotechnology is not a new concept. According to Harper (2003), thousands of years ago, the Romans and Chinese used gold nanoparticles to color stained glass. Put into perspective, every time a person lights a match, *fullerenes* (a 20-hexagonal and 12-pentagonal rings molecule composed of carbon) are produced. Fullerenes are considered a building block of modern nanotechnology (see Van Nedervelde, 2006). Nanotechnology materials ("nanomaterials") are used in contemporary sunscreens, additives in plastics, computing, and textiles (Nohynek, Lademann, Ribaud, & Roberts, 2007).

Developing future engineered nanomaterials (ENMs) is expected to explode with incredible innovations as new nanomaterials are developed and infused for consumer use

(Roco, 2006). For example, companies are currently manufacturing auto paints that produce a micro-hardness barrier to resist impacts and scratches. In the medical field, ENMs are being developed to deliver medicines to destroy cancer cells (Keim, 2005). But, pause to consider this question: What is the downside to these incredible possibilities—what are the expected hazards of minute particles on the human body and what does this mean for our workforce?

Nanotechnology Safety

Nanotechnology will likely grow into a trillion dollar market transforming the global economy (Hsieh, Tsai, Chen, & Chang, 2009). When new products are developed, workers' safety must be considered to prevent harm and litigation. Although there are some (preliminary) guidelines to protect against ENMs (NIOSH, 2009; Trybula & Fazarro, 2008), educators are faced with developing curriculum to teach workers how to protect themselves at the nanometer level. Will we have a workforce ready for this coming reality?

Companies that manufacture new ENMs must incorporate safety protocols to ensure worker safety. Today, the growing workforce faces potential exposures, yet lacks reliable information about the specific nature of the risks posed by ENMs, or about how to work safely with ENMs (Kulinowski & Jaffe, 2009; NIOSH, 2009).

Safety tools that permit the safe handling of many hazardous materials are based on decades of collecting and publishing ENM data by the National Institute for Occupational Safety and Health (NIOSH) and research communities. However, there is still a need to focus on developing control practices based on the ENMs' character and levels of exposure for worker safety (Vishwakarma, Samal, &

Manoharan, 2010). NOISH (2009) stressed the importance of ENMs that present new challenges to understanding, predicting, and managing potential health risk to workers.

The Future Nano Workforce: Characterizing Generation "Y"

Teaching the upcoming workforce (often referred to as Generation "Y" or "Millennial" students describing those born between 1980 and 2000~~)~~ has been challenging. Educators reported struggles to motivate these students to achieve the learning outcomes in academic courses (Eisner, 2004). To compound the problem, college students are rarely majoring in STEM areas, leading to critical shortages in the U.S. of the human expertise needed to remain competitive in technological advances (Atkinson, Hugo, Lundgren, Shapiro, & Thomas, 2007). Without an adequate number of STEM majors enrolling into future nanotechnology programs, the United States will fall behind in developing the nano workforce.

Seymour & Hewitt (1997) indicated that, overall, students cannot maintain academic success in STEM fields due to poor teaching, dull introductory courses, lack of encouragement and role models. Dr. Matthias Pleil, Director and Principal Investigator for the Southwest Center for Microsystems Education at the University of New Mexico stressed:

> It is imperative we all engage our students to consider a career path in STEM driven careers, particularly the future technicians who will support the micro and nanotechnology workforce. New and innovative delivery of education will keep these tech savvy students engaged so that connections between STEM foundation concepts and their future jobs are clear

(Matthias Pleil, personal communication, March 3, 2011).

Infusing Nanotechnology Safety with Education

As generation "Y" or millennial students are constantly connected to technology and are very tech-savvy having grown up with mobile phones, laptops, Xboxes and iPods, even creating their own texting language, they expect their education and work experiences to be integrated with sophisticated technologies (Larrabee & Robinson, 2006). Educators have often reported that these students prefer an environment where they can be immersed into highly focused activities with their favorite sophisticated technologies. This immersion can be considered in light of the theory of flow.

Csikszentmihalyi (2000) defined *flow* as people being "intrinsically motivated, interested in challenging tasks at hand, being unconscious of themselves while performing the tasks, feeling a unity between consciousness and activities, and oftentimes losing the sense of physical time" (Csikszentmihalyi, 1990, pp. 48-66). A person's Flow experience is achieved when there is a balance between the skill of the participant and the challenges of the activity and skill "refers to an individual's capabilities to deal with tasks encountered during activities, whereas challenge means the degree to which individuals find it difficult to cope with specific tasks involved" (Csikszentmihalyi, 1990, pp. 72-77). See figure 2, The Function of Flow.

Figure 2. The Function of Flow

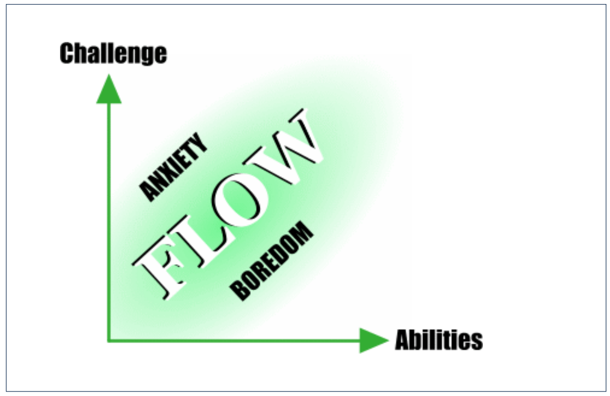


Figure 2. Flow Zone as a function of the level of challenge versus the level of abilities as described by Csikszentmihalyi (1998) adapted from “Flow in Games” by J. Chen, Retrieved from http://www.jenovachen.com/flowingames/introduction.htm

Conceptually, the experience of flow transpires when the degree of challenge equals, or is slightly higher than the degree of skill. In addition, if the degree of challenge is in excess of skill, the person may become frustrated, and the person may become bored if the challenge is too much lower than their skill level. Another way to think about flow is to “regard it as a mental mode represented by the combination of some characteristics that individuals experience” (Shin, 2006, p.706).

In the context of this article, for example, “Flow represents the extent to which: (1) the user perceives a sense of control over the computer interaction, (2) the user perceives that his or her attention is focused on the interaction, (3) the user’s curiosity is aroused during the interaction, and (4) the user finds the interaction intrinsically interesting” (Trevino & Webster, 1992, p. 542).

Researchers Hoffman and Novak (1996) define flow in terms of the experience of flow (intrinsic enjoyment, loss of self-consciousness), behavioral properties of the flow activity (seamless sequence of responses facilitated by interactivity with the computer and self-reinforcement), and its antecedents (skill/challenge balance, focuses attention, and telepresence).

Defining flow provides a direct correlation to the characteristics of generation 'Y'. Using their strengths, provides an opportunity for educators, especially those who teach safety education, an edge to offer another method of delivering safety education in a way that will naturally fit the Generation 'Y' cognitive abilities.

Nanotechnology Safety Education in the Virtual Environment

There is a myriad of choices for the online delivery of training and education available to modern educators. For instance, online training and education courses can be delivered primarily asynchronously (where most or all interaction is not in real-time, but at student and instructor convenience) through the use of Course Management Systems (CMS) also referred to as Learning Management Systems (LMS) on platforms such as Blackboard™, Pearson's eCollege™, Moodle™, and Sakai™ (Gilfus, 2010). Synchronous (real-time) delivery of training and educational experiences can also be provided through web videoconferencing systems such as Centra™, Cisco's WebEx™, Adobe Connect™, and Elluminate Live™ delivery systems (Tucker, 2011). It is noted that some platforms (such as Elluminate Live™) can be embedded within a CMS/LMS for synchronous interaction between students and instructor through an integrated approach. Relatively new on the scene for educators, are three-dimensional (3D) virtual worlds such as Second Life™ (SL). Previously used primarily for entertainment, SL and other virtual worlds have been adapted by educators and trainers for synchronous virtual learning and virtual training (McWhorter, 2010; Raisor & McWhorter, 2011; Short, 2010, 2011) with approximately 200 higher education institutions world-wide having implemented learning activities in this virtual world (Molka-Danielsen & Deutschmann, 2009).

A recent study in Second Life found the media-rich, highly interactive environment to be conducive for adult learning. This *persistent digital world* (it will still be online and functioning even if you log off) has many of the enticing graphics of a modern video game~~s~~ but has the ability for users (and educators) to create their own user-made educational content. The researchers of the study remarked that their study participants "recognized social presence—the phenomenon of feeling you are in the same geographical location as others, due to accessing the virtual world through a self-customized avatar and use of gestures thereby facilitating 'the sense of being'" (Mancuso, Chlup, & McWhorter, 2010, p. 690).

Further, Bingham and Connor (2010) noted that virtual worlds such as SL provide a "digital simulated experience" (p. 130) where learners interact with user-made content and other avatars in a synchronous online environment through the use of voice and text chat. Further, they reported that virtual worlds have been useful for virtual field trips, offsite meetings, 3D modeling of buildings, manufactured products and molecular structures, and "when people need training for work in hazardous environments" (p. 131). Such simulated environments have included projects such as the blasting simulations in the University of Derby's granite quarry, emergency preparedness training simulations, a U.S./Canada Border simulation training for border crossing guards, a simulated coal-firing power plant, a tour through a virtual nuclear reactor, and various military simulations (Gronstedt, 2011).

The rationale for consideration of a virtual world for nanotechnology safety education is four-fold. First, the use of a virtual world poses no physical safety hazards (such as exposure to nanoparticles that might prove dangerous) while a trainee or student is learning appropriate safety precautions through simulated experiential learning in a virtual world (Gronstedt, 2008; Jarmon, Traphagan, Mayrath, & Trivedi, 2009). The virtual world provides the student with an "immersive experience in which he or she could not [safely] otherwise venture" (Kapp & O'Driscoll, 2010, p. 219). A virtual world environment can provide "PreLab or PreField" experiences such that students gain familiarity with "typical" nano-related environments and potential hazards as well as safety protocols required in the workplace. By interacting within the 3D environment, students will become accustomed to such required safety practices in a novel way.

A second rationale for safety training and instruction in virtual environments is cross-collaboration from various geographical locations. Due to the inherent web-based technologies available in 3D virtual worlds such as Second Life, students from various geographical locations can meet online in one course without leaving their home or office. This practice saves both time and money for students and instructors (Mennecke, McNeill, Roche, Bray, Townsend & Lester, 2008; Short, 2011).

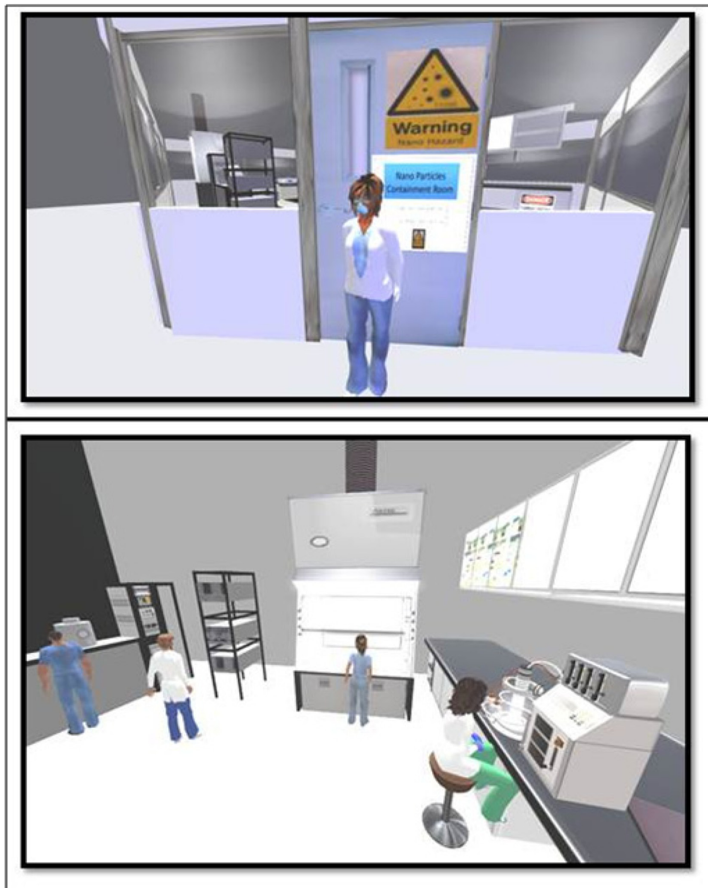
Third, the utilization of a virtual world allows the implementation of nanotechnology safety education without the need for expensive equipment at its onset. Not every institution will have access to the state-of-the art equipment or nanotechnology labs at their institution, but through 3D modeling and animation technology available in virtual worlds such as SL, students can become familiar with the appearance, purpose and workings and safety procedures for such equipment. This experiential knowledge will begin the development of a competent nanotechnology workforce.

A fourth rationale for utilizing a virtual world for nanotechnology safety education is due to the fact that virtual environments are easily accessible through existing computer lab infrastructure as well as student access at home; therefore, existing technology and instructors can be leveraged for the new safety courses recommended in this conceptual article with little or no additional expense. However, it is noted that developmental funds may be needed for the design of the virtual environment when instructional technology personnel and instructors do not have the 3D modeling experience needed to create the new nanotechnology lab spaces in virtual worlds.

For the purpose of this conceptual article, we illustrate how an existing Nanoparticle Containment Room at Texas State University-San Marcos has been adapted for instruction within the virtual world of Second Life. Our "proof of concept" can be seen in the graphical representations in Figure 3 below. In this figure, the reader will notice that the upper graphics are actual digital photographs of the containment room at TSU-San Marcus while the two pictures below were taken in the Nanoparticle Containment Room within the virtual world of Second Life. Approximately 50 geographically-disbursed students (via avatar) can participate in a Nanotechnology Safety Course by learning procedures in areas outside the containment room such as appropriate protective gear and safety protocols. The virtual lab itself is equipped with numerous interfaces to web browsers for streaming videos and other learning materials. We envision that once students acquire a basic knowledge of their surroundings and put on necessary safety gear, they will be introduced to the containment room itself.

Figure 3. Physical and Virtual Nanoparticle Containment Room Depictions

ACTUAL NANOPARTICLE CONTAINMENT ROOM
Photos Courtesy of: Jitendra S. Tate, Ingram School of Engineering, Texas State University-San Marcos



VIRTUAL NANOPARTICLE CONTAINMENT ROOM
Photos Courtesy of: Krystle McWhorter,
KR Virtual Designs

Figure 3. Depictions of actual nanoparticle containment room in physical and in virtual world settings. Actual Nanoparticle containment room pictures courtesy of J. S. Tate, Texas State University, San Marcos; Virtual nanoparticle containment room pictures courtesy of K. A. McWhorter, Copyright 2011, krvirtualdesigns@gmail.com

Conceptual Model: Multi-Institution Collaboration to Curriculum Design to Virtual Environment

According to (Genaidy & Karwowski, 2006) the pillars of nanotechnology safety education should contain the following:

> A roadmap and a guide should be developed for individual health and safety promotion and protection; focus groups should be established to advance integrated solutions and issues of immediate concern to individual health and safety in different nano-manufacturing sectors/environment/disposal activities, and health of public consumers of nano-based products (p.253).

For the purposes of this article, the authors will use the Genaidy and Karwowski (2006) as well as Fazarro (2011) models to illustrate a design for a nanotechnology safety education course. Both models emphasize the education and research elements. Fazarro (2011) used a summative, holistic/multi-institutional collaboration approach to pull the research and teaching oriented institutions and industries together for a nanotechnology safety education program. In addition, this model focuses on the institutions' strengths to create individual niches to form a synergy for laterally diffusing knowledge for improving the nanotechnology safety education. In contrast, Genaidy and Karwowski's (2006) model is formative with purposeful objectives for developing a nanotechnology safety education course integrated with the Fazarro (2011) model to create a conceptual framework (See Figure 4) for developing a virtual world course –*Introduction to safe handling of nanomaterials*.

Figure 4. Conceptual Model for Creating a Nanotechnology Safety Course in a Virtual World Environment

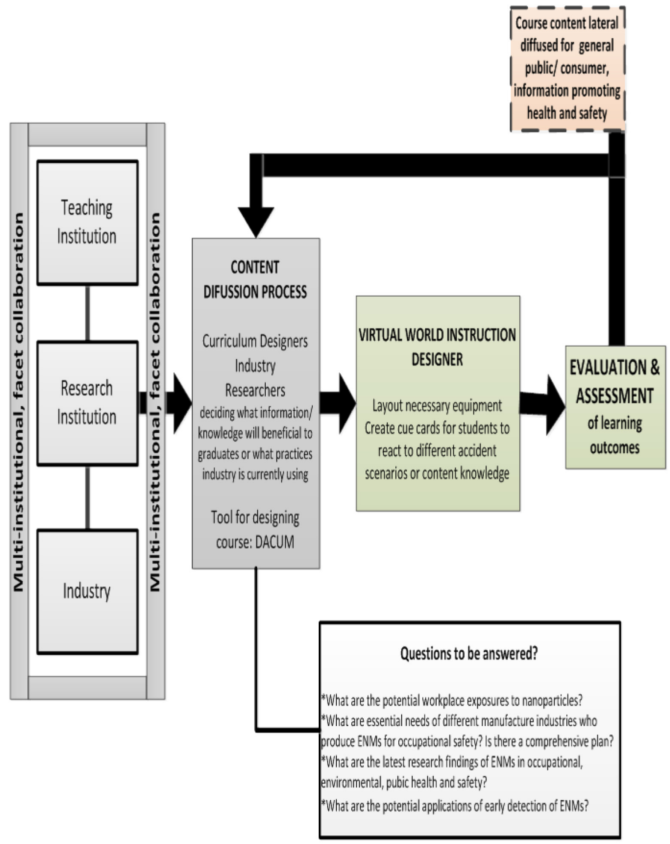


Figure 4. Conceptual Model for creating a nanotechnology safety course in a virtual world environment. Adapted from "Lateral diffusion of nanoeducation: Developing the new workforce", by D. Fazarro In J. Light Feather & M.F. Aznar (Eds.), Nanoscience education, workforce training, and K-12 resources, p. 210. Copyright 2011 by Boca Raton: CRC Press. Adapted from "Nanotechnology occupational and environmental health and safety: Education and research needs for an emerging interdisciplinary field of study," by .A. Genaidy, & W. Karwowski Human Factors and Ergonomics in Manufacturing, 16 (3) pp. 250 & 252. Copyright 2006 by Wiley InterScience.

This model is designed to extract new/cutting-edge knowledge for pushing information into course content. In order for this model to work, educators and industry personnel must be open to 'forward-thinking' and 'out-of-the-box' thinking in order to address the educational needs in nanotechnology education. The model illustrates the following steps for developing a nanotechnology safety education course: Beginning with feedback through collaboration between industry and institutions, decisions are made as to the content to be presented, then a visual layout of the necessary equipment and instructions by virtual world instructional designer(s) is created followed by the development of evaluation and assessments of learning outcomes with diffusion to the public and consumers for promoting health and safety.

Discussion

In this article we 1) informed educators in the field about nanotechnology, 2) built the case for nanotechnology safety education to prepare the workforce for this emerging industry, and 3) provided a conceptual framework to design and implement nanotechnology safety education in a virtual environment. This article provides a conceptual framework for the designing and implementation of a nanotechnology safety course in a virtual world environment. The authors put forth this article as a 'future shock' of things to come as nanotechnology becomes increasingly more prevalent in our society. Collaboration between industry and academia is crucial to developing the new workforce for the 21st century.

The authors argue that complacency is not an option for educators. As we know, the new generation of learners is challenging to educators across the U.S.; however, this new generation must become our future leaders to sustain the country's technological edge. Even though educators are diligently pushing toward a more vibrant workforce, there is still a dark cloud looming over the country's inability to get generation 'Y' interested in STEM fields. Post-secondary institutions should develop and diffuse content into curriculum courses using 3D and other motivational means. Furthermore, there is a need to continue research to uncover interventions which will capture the interest and enhance the abilities of the upcoming workforce.

Education in the virtual world for nanotechnology education is a new method and possibly the key for providing a more authentic online learning environment for current and upcoming students who are constantly connected to technology. Although understanding of required nanosafety procedures and actual experience with equipment is ideal, it is not always practical or available, making virtual learning a viable alternative. In addition, to lure generation 'Y' students in the STEM disciplines, educators must conform to how generation 'Y' socially interacts with technology. Thus, educators must examine and likely redefine their educational philosophies, such as essentialism, progressivism, constructivism and existentialism to incorporate interactive instructional models to maximize the learning outcomes. The reality that all educators must consider is the virtual world is not a panacea, but a viable tool in the educator toolbox to reach out to learners at a distance.

Implications for Further Research

Our next step in the research journey is to begin introducing higher education students into the virtual environment depicted in this article to determine if our "proof of concept" provides positive learning experiences in the area of nanotechnology safety education. Evaluation of the experiences of the students (See Figure 4) will give feedback for the fine tuning (as well as collaborating with experts in the area of nanotechnology) for continued iterations of refinement of the 3D safety education environment model.

A second step on the research journey will involve examining the instructor's skill set needed when teaching in real-time virtual environments. We suspect that the current competencies for trainers and educators will need to be augmented to work successfully in integrated virtual environments, particularly for those sophisticated technologies with immersive and social characteristics.

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A Case Study: Teaching Engineering Concepts in Science

David R. Stricker
University of Wisconsin-Stout

Abstract

This study was conducted to describe a high school engineering curriculum, identify teaching strategies used to increase math and science literacy, and discover challenges and constraints that occur during its development and delivery, as well as what strategies are used to overcome these obstacles. Semi-structured interviews were conducted with the engineering instructor. In addition, students were observed and curriculum documents, teacher lesson plans, and teacher resources were examined. Concepts created the platform for delivery, curricular trial and error was at work, science and engineering competitions were leveraged as a basis for learning activities, and project based learning and teaching was critical. There was a clear emphasis on creative thought and work. Assessment of student learning was dubious and elusive and stakeholders tended to be uneasy with this new pedegogy. Financial and instructional support through business partnership and administrative support were found to be critical strategies used to overcome obsticles identified.

David Stricker is an Assistant Professor at University of Wisconsin-Stout. He can be reached at strickerd@uwstout.edu

A Case Study: Teaching Engineering Concepts in Science

The focus on improving science, technology, engineering, and mathematics (STEM) education for America's children can be traced back to the days of Sputnik and beyond. However, compared with advancements then, it has been argued that today technological development and industrial growth are increasing at an exponential rate with expanding global application (Brophy, Klein, Portsmore, Rogers, 2008). Consequently, amid concerns that the United States may not be able to compete with other nations in the future due to insufficient investment today in science and technology research and STEM education, funding initiatives such as the American Recovery and Reinvestment Act (U.S. Department of Education, The American Recovery and Reinvestment Act of 2009: Saving and Creating Jobs and Reforming Education) and "Race to the Top" competitive grants have been enacted in 2009 in an effort to offer substantial federal support for such initiatives (U.S. Department of Education. President Obama, U.S. Secretary of Education Duncan Announce National Competition to Advance School Reform). The support structure for STEM education does not end with tax dollars. Large private companies such as Time Warner Cable have committed $100 million in media time, and the MacArthur Foundation is supporting "National Lab Day" that will include, among other initiatives, a year-long effort to expand hands-on learning methods throughout the country.

Specifically, within the STEM focus, engineering education supports the attainment of a wide range of knowledge and skills associated with comprehending and using STEM knowledge to achieve real world problem solving through design, troubleshooting, and analysis activities (Brophy, et. al., 2008). The arguments for including engineering education into the general education curriculum are well established. Some are motivated by concerns regarding the quantity, quality, and diversity of future engineering talent (American Society for Engineering Education, 1987; National Academy of Engineering, 2005; National Research Council, 1996; International Technology Education Association, 2002) and others by the basic need for all students, in their pursuit of preparing for life, work, and citizenship in a society inundated with technology, to possess a fundamental understanding of the nature of engineering (Welty, 2008).

In an attempt to address this issue, there have been a number of curricula designed to infuse engineering content into technology education courses (Dearing & Daugherty, 2004). Each of these programs proposes teaching engineering concepts or engineering design in technology education as a vehicle to address the standards for technological literacy (International Technology Education Association, 2000/2002). Similarly, the National Academy of Engineering (NAE) publication *Technically Speaking* (Pearson and Young, 2002) emphasizes the need for all people to become technologically literate to function in the modern world. However, despite this clear need, within the technology education profession itself, the appropriate engineering curriculum required for implementation, particularly at the high school level, remains unclear. Indeed, engineering curricula exist that have been designed for implemetation, not in technology education, but rather in math and science classrooms. As a result of the choices available to teachers and school administrators, the extent to which the most effective way of delivereing engineering content to high school students remains unclear.

Problem Statement

Since there is a lack of consensus on how best to deliver engineering curriculum to high school students, there is a need to identify attributes of programs that have been successful in doing so. As a result, this research study was designed to examine such a high school engineering program led and taught by Timothy Jump of Benilde-St. Margaret's, a Catholic, ~~a~~ college preparatory school for students in grades 7-12, located in St. Louis Park, Minnesota. While *Advanced Competitive Science* is the name given to this program offered to students in grades 10-12, *engineering education* is the program's goal and, therefore, this phrasing will be used from this point on to facilitate a general understanding. This case study examined the attributes of this highly regarded secondary school engineering education program because of its organic approach to curriculum development and unique focus on engineering concepts borne of the motivation to reinforce math and science concepts.

Research Questions

Five semi-structured interviews were conducted with the instructor of the high school engineering program previously mentioned in order to identify ways of successfully delivering engineering content at the high school level. In addition, classroom observations were made and curriculum documents and teacher lesson plans were gathered and examined. The results will focus on that part of the research which proposed to:

(a) describe high school engineering curriculum developed with the sole purpose of delivering math and science literacy;

(b) identify teaching strategies used at the high school level in the process of delivering math and science literacy in the context of an engineering program;
(c) identify challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts; and
(d) strategies used to overcome these obstacles.

A pre-interview with the instructor was also conducted to determine what he considered to be relevant data to collect in order to capture the experiences. As a result, the following questions were used to guide the interviews:

1. Why have you chosen to implement engineering into a high school science program?
2. What changes have you had to make to your science curriculum to teach engineering concepts?
3. What new strategies have been generated in order to successfully implement engineering curriculum?
4. What curriculum resources have been most helpful to you in order to make this change?
5. What equipment, tools, and software have been added to your classroom for the purpose of effectively delivering engineering concepts?
6. What challenges or constraints have you faced when seeking to implement engineering concepts into your classroom?
8. How have you overcome those identified challenges/constraints?
9. What advice would you give a technology teacher who seeks to implement an engineering course?

Literature Review

The arguments for including engineering education into the general education curriculum are well established and it has been suggested that the technology education field align itself with engineering for a number of reasons: to gain acceptance by academic subjects; serve as an invitation to the engineering community to collaborate in the schools; increase the social status of technology education; and ease the justification of the field in schools' communities (Bensen & Bensen, 1993). Other leaders in technology education, as well as the engineering education community have also identified the role K-12 engineering education plays in the success of postsecondary engineering education (Douglas, Iversen, & Kalyandurg, 2004; Hailey, Erekson, Becker, & Thomas, 2005).

However, even from within the technology education profession itself, the appropriate engineering design content required for implementation into high school technology programs remains unclear. In an attempt to address this issue, there have been a number of curricula designed to infuse engineering content into technology education courses such as Project ProBase, Principles of Engineering; Project Lead the Way, Principles of Technology; Engineering Technology; and Introduction to Engineering (Dearing & Daugherty, 2004). Each of these programs proposes teaching engineering concepts or engineering design in technology education courses as a vehicle to address the standards for technological literacy (International Technology Education Association, 2000/2002).

To educators, curriculum designers, and educational researchers, the benefits of significant engineering related activities such as design, trouble shooting, and reverse engineering, are well known and serve as popular instructional models in science, math, and technology education in order to meet many of their standards (Brophy, et. al., 2008). In fact, the National Science Education Standards emphasize the importance of how design and understanding of technology inform students' understanding of science (National Research

Council, 1996). Also, the National Mathematics Standards (National Council of Teachers of Mathematics, 2000), who have been viewed as a complement to science standards, aim to develop competencies (a fluent and flexible sense for numbers, mathematical operations and representations to perform analyses as a part of problem solving, and estimate mathematical calculations rather than relying on paper and pencil procedures just to name a few) that are integral to and can be uniquely addressed by engineering and design curricula. To that end, curricula such as The Infinity Project, Learning By Design, Models and Designs, and A World in Motion were developed chiefly to promote understanding of math and science concepts by employing engineering design activities with no direct intent to promote technological literacy in technology education courses whatsoever (Welty, 2008). Very little research has been conducted with regard to how particular engineering education experiences differ from mainstream science and math instruction (Brophy, et.al, 2008). How do high school programs designed specifically to increase science and math literacy rather than technological literacy approach engineering design curriculum? Said differently, when many of the engineering curricula is designed to be infused into technology education programs, how do high school engineering education programs derived organically from a science and math emphasis approach engineering design curriculum?

Also, the curriculum products mentioned above are prescriptive in their design and approach to delivering engineering concepts to students. These curricula are designed to deliver this content via objectives. Once these objectives have been established, a curriculum subsequently suggests the content to be taught, the methods to deliver it, and the eventual assessment of the material (Saylor, Alexander, and Lewis, 1981; Tyler, 1949). This *deductive* model of curriculum development diagrams the process of how many curricula are designed – engineering curricula being used in technology education, science, and math included.

However, a *descriptive* model of curriculum design takes a different approach. Walker (1971) described this type of model as being primarily descriptive which is in contrast to the classic prescriptive model described above. Coining this model as *naturalistic*, Walker explains that it entertains objectives, learning activities, and evaluations as cyclical in nature and a means to inform the *platform* that established the basis for the curriculum. This *platform* is defined as essentially the shared beliefs or principles that guide the developers of the curriculum and is developed through discussion regarding the developers' values, beliefs, perceptions, and commitments relative to the curriculum in question. This mix of positions lays the groundwork for a deliberation that takes place involving the issues with the current curriculum being used and ways to eliminate frustration with its inadequacies. After this is completed, however, the actual design of the curriculum can begin (Walker, 1971).

The organic nature of this type of curriculum design is obvious and is in contrast to the design of the curricula currently being used to infuse engineering design into technology education courses and programs, as well as in math and science classrooms.

Method

In considering research tactics for this study, the need for a method to investigate the phenomenon of engineering curriculum developed and taught naturalistically to deliver math and science concepts lent itself well to a case study strategy. Semi-structured interviews were conducted with the classroom teacher, classrooms were observed, and curriculum documents and teacher lesson plans were examined in an effort to carefully develop an understanding of the complexities of this case (Creswell, 2007). Timothy Jump was selected for this case study because he represented a specific phenomenon and served as an archetype of a teacher who had created and implemented an engineering curriculum developed via the naturalistic method (Gall, Gall, & Borg, 2007).

After assembling data from the interviews, classroom observations, and collected curriculum documents, analysis of the data began by review of the interview transcriptions, field notes, and curriculum documents. Microsoft Word was used organize the research data for analysis via tables, meaningful groupings, and combining and synthesizing data across multiple sources (Ruona, 2005).

Data Analysis

Questions were asked in order to identify teaching strategies used to deliver math and science literacy in the context of an engineering program. Specifically, efforts were made to have the subject describe high school engineering curriculum developed with the sole purpose of delivering math and science literacy, identify challenges and constraints that occur during the delivery of high school engineering curriculum, and outline strategies used to overcome these obstacles. Five interviews in all were conducted, lasting 60 minutes each. The participant was interviewed in his own classroom and was recorded with a tape recorder while the researcher took notes. Interview recordings were transcribed and examined for themes by the researcher. The transcripts were sent via email to the participant for review, to observe themes being identified, and to clarify any information. Themes emerged from the transcribed interviews through the use of coding and, in tandem with the research objectives, were used as organizers to report the results in the study. The participant's responses were coded through a process of horizontalization demonstrating the participants experiences (Moustakas, 1994) and categories defined by similar statements as they related to research questions (Creswell, 2007). Inter-rater reliability was established with the aid of collaboration with the interviewee. Both the researcher and the interviewee reviewed transcripts separately.

Participant

Timothy Jump is the developer, teacher, and director of the engineering program (Advanced Competitive Science) at Benilde-St. Margaret's School in St. Louis Park, MN. He received his BFA from Southern Methodist University in 1983, as well as teaching certificates in mathematics and chemistry in 1985. Jump also holds an art certification from The University of Dallas received in 1987. Mr. Jump's honors include membership in Phi Theta Kappa National Honor Society; Kappa Delta Pi Educators National Honor Society; and Who's Who Among America's Teachers; among others. Along with personal honors, Jump's engineering teams at Benilde-St. Margaret's have posted honors including a Certificate of Technological Innovation from the U.S. Department of Commerce; Best Design for Manufacturability from the Society of Manufacturing Engineers; National Engineering Design Challenge National Champions; RoboCup Rescue Robot League US Open Champions; and a top ten finish at the RoboCup Rescue Robot League World Championships.

Research Objective #1

Describe how high school engineering curriculum developed with the sole purpose of delivering math and science literacy.

Theme 1: Concepts create the platform.

As mentioned, Walker (1971) described a *naturalistic* model of curriculum development that entertains objectives, learning activities, and evaluation as cyclical in nature. Developed through discussion regarding the developers' values, beliefs, perceptions, and commitments, a *platform* for the curriculum is formed. This is fortified by discussions regarding the developers' values, beliefs, perceptions, and commitments relative to the curriculum in question. This mix of positions lays groundwork for a deliberation that takes place that involves the issues with the current curriculum being used and ways to eliminate frustration with its inadequacies. After this is completed, however, the actual design of the curriculum can begin (Walker, 1971). Jump noted conceptual learning was at the basis of developing the ACS (Advanced Competitive Science) curriculum. This mission of sorts laid the groundwork for the *platform* of the ACS program.

> *Jump.* I must have had a dozen engineering textbooks and everything I've pulled out is all college textbook stuff. There is nothing for high schools… this book (*Engineering Mechanics: Dynamics*, 3rd edition by Bedford & Fowler (2002) is full of math problems just like any other mechanical engineering textbook, but I thought that their explanation of the concepts was very good… I wasn't a mechanical engineer, I didn't go to engineering school.

The emphasis on conceptual learning of math and science content is made explicit in the program description:

> "Advanced Competitive Science (ACS) is a conceptual engineering program in which students explore mechanical and electrical systems through fabrication and assemblies, design processes utilizing 3D modeling tools, and control systems incorporating sensor interfacing, data collection, motion control and embedded logic programming… develop advanced problem-solving skills and sub-level mastery of formal teachings in science and mathematics as a result of direct application of these knowledge sets. By engaging students in the iterative process of problem formulation, abstraction, analysis, design, prototyping, testing and evaluating, ACS expands student development beyond information concentricity and toward innovation and entrepreneurialism…" (Benilde-St. Margaret's, 2010).

Jump created a series of modules for his first year Engineering 1 students with significant conceptual focus. Although there are specific skill related topics in each of the modules, the essence of topics are focused on reinforcing concepts such as mathematical relationships, design, friction, force, structures, loads, mobility, mass, gravity, moments, couples, supports, simple machines, control, evaluation, prediction, problem solving, and systems.

Theme 2: Curricular trial and error.

As noted, once the platform of a naturalistically formed curriculum is established, the actual design of the curriculum can begin. A popular cyclical approach to this process involves revisiting the steps used to create the platform: selecting objectives; selecting and organizing content; selecting and organizing methods; and evaluation (Nicholls and Nicholls, 1981). Jump mentioned that this iterative approach is as evident today in his curriculum development process as it was at the onset of the ACS program.

Specifically, he explained that because there was no engineering curriculum in existence at the time the ACS program was in its infancy, there were no guidelines as to how the program should be structured or focused.

> *Jump.* …our first semester I had 6 kids that I just kind of recruited to start [the ACS program]… There was no curriculum… no textbook… we just grew it independently (of science), which gave us a lot of freedom… and there is no accreditation for engineering courses so we don't have to deal with state requirements. It really allowed us to just experiment… Then as the kids were graduating, we were getting feedback from the colleges. "Oh this was great, I knew this and none of the other kids did" or "you know we did that but that didn't help me at all."

The positive effects of bringing different curricular content together in a novel ways, such as engineering can provide, is well established. Indeed, the idea of integrated curriculum has been popular because of its potential to prevent students' fragmented view of the curriculum as a more holistic approach to content. This type of curriculum aims to develop student understandings through continuous interaction, conversation, and discussion (Pidgon & Woolley, 1992). The goal of an integrated curriculum approach is to extend and refine students' developing knowledge (Murdoch & Hornsby, 1997). One model used to plan integrated curricula is termed "threading". Threads for helping students make connections between various content areas relate to four main "ways of working". These include cooperating and interacting, reasoning and reflecting, imaging and inquiring, and assessing and evaluating (Murdoch and Hornsby, 1997, pp. 14-15).

Research Objective #2

Identify teaching strategies used at the high school level in the process of delivering math and science literacy in the context of an engineering program

Theme 1: Science/engineering competitions were leveraged.

One of the most common approaches to training engineering students to think creatively is presenting them with complex, open ended design problems that are often couched in competitions. These types of problems are designed to represent "real" scenarios or issues and have many possible solutions (Lewis, 2004). An example is the curriculum Roth (1996) identified in his study to understand the process of designing, Engineering for Children: Structures (EFCS), provides such an experience for students to form engineering knowledge in the realm of structures. However, Roth is careful in pointing out that these activities, whose core goal is to have students create bridges as part of an ongoing engineering competition for constructing a link between two sections of a city, are not designed specifically to "transmit legitimated and canonical engineering knowledge" (p. 130).

Although Jump would agree with the educational value of engineering competitions posed by Roth, to say he chose to focus on competitions because of this potential would be disingenuous. Rather, Jump simply chose competitions because of the appeal they had with his physical science students when ACS was in its infancy – they were a hook. The National Engineering Design Challenge became an attractive curriculum target because of its ability to focus design and engineering thinking on socially significant problems that could be tackled within the school schedule.

> *Jump.* I was recruiting my IPS (Introductory to Physical Science) kids… we were just on the computers and looking stuff up and doing research to find out what

> other types of competitions... FIRST Robotics was the very first thing we did along with something called National Engineering Design Challenge… we just started doing more and more engineering type of competition and got away from all the say the Quiz Bowl type of things…

As mentioned, because of this drive to engage students in science through competitions, Jump was initially going to pursue all branches of science because of the variety and availability of such events as Science Bowl, Science Olympiad, Science Fairs, FIRST Robotics, and the National Engineering Design Challenge. Since these contests were taking place in his physical science class at the time, before the ACS program was established, Jump explained that his motivation was to locate events that encouraged students to "design and build".

> *Jump.* I was really focusing on the ones (contests) that made them design and build, because this grew out of freshman physical science when I had them doing design and build projects…

Theme 2: Project based learning and teaching.

Problem solving and Problem Based Learning (PBL), regarded as "…an orientation towards learning that is flexible and open and draws upon the varied skills and resources of faculty and students" (Feletti, 1993, p. 146), have become central themes that run through contemporary education. Jump cites how a project based pedagogy, borne of novel problem posing, was central to the success of ACS program.

> *Jump.* You've got to do it… It's not just some two dimensional somewhat abstract concept. How do you really make a lever work? There are other issues with the lever, the fact that oh, what happens if the load is too much and the lever itself breaks? What about the bending that happens with it? What about the fulcrums that didn't slide out and screwed out? It was important

> for the kids to have a result… Things moving and doing stuff, empowering them to be able to create something that does the same thing. The problem solving and the creativity it's like art projects… How do I take ownership of my intellect, my creativity.

Jump began negotiations with the schools administration for a single period within the school day in order to experiment with a science based course with a hands-on, problem solving focus. In the beginning, projects consisted of mouse trap cars, Rube Goldberg machines, and other science projects used to reinforce concepts that involved simple machines, data collection, analysis, optimization, design, predictive analysis, as well as the process of trial and error.

> *Jump.* The vision of this program is how do I get the people ready to do that creative engineering? Now they could easily take that same mental structure and be an artist, be a business person, because now how do find more creative ways to manage money? More creative ways to make processes cost less, but be more effective.

Theme #3: Emphasis on creative thought and work.

This notion of *creative engineering* is well founded in technology and engineering literature. The need for structures to withstand harsher environments, be built to greater heights, with greater controllability, and be safer and more economical, signals the demand for creativity in engineering practices (Teng, Song, & Yuan, 2004). It has been said that there is pressure placed on engineering educators to develop ways to foster creativity in engineering students in order to answer the demands of contemporary society and industry that are impacting the engineering profession worldwide (Mitchell, 1998). In the last two decades, engineering education has indeed focused on enhancing students' creativity to meet these various needs (Cropley and Cropley, 2000). This change has necessitated a shift away from traditional engineering curricula focused on physics, math, and mechanics. Industry now requires engineers to possess problem solving abilities (Grimson, 2002). Subsequently, one of the most common approaches to training engineering students is presenting them with complex, open ended design problems, much like what Jump discovered in the competitions he employed. He explained that the product produced by such an event has proven to be a very powerful motivational tool for learning.

> *Jump.* So the energy, the emotional, the intellectual, the cognitive engagement in trying to understand something was so different when we were doing these engineering type projects…
>
> The problem solving and the creativity it's like art projects… kids get very attached to their art work. Even if it's no good you're trying to explain to them why it's no good. They get upset because they take ownership of that art work... To me Engineering is that creative… how do I look at the world around me and make whatever it is better.

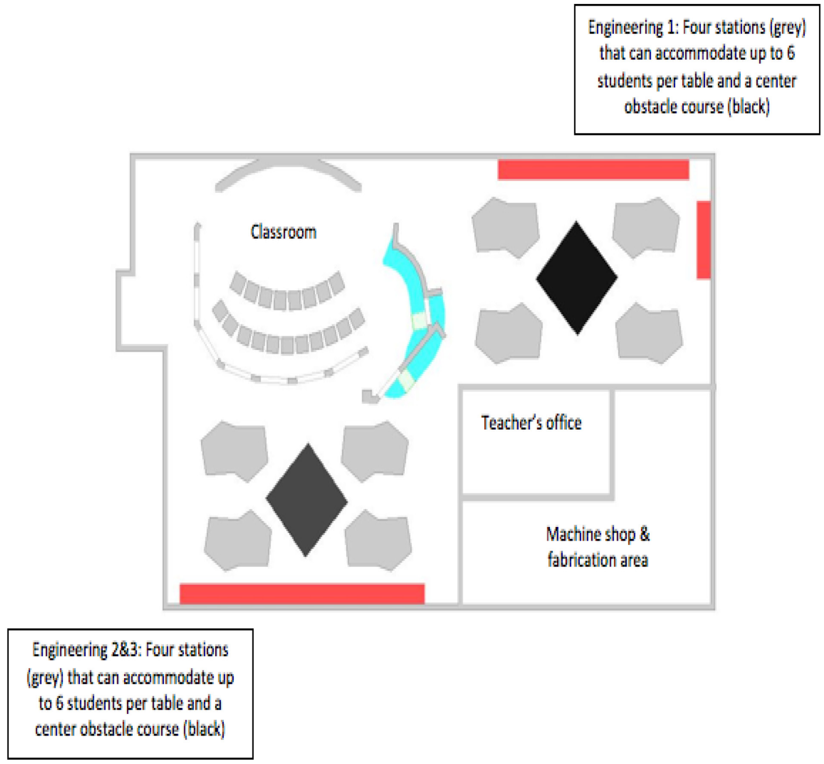
Kersting (2003) acknowledged that there are possible similarities and differences in creativity as it relates to people in the sciences and arts: "Science has to be constrained to scientific process, but there is a lot less constraint on artists. Many artists come from more chaotic environments, which prepares them to create with less structure" (p. 40). Larson, Thomas, and Leviness (1999) commented that although there may be opportunity for creativity to exist in both the arts and sciences, there is a possibility that creativity in engineering might be different from creativity in the arts: "A distinguishing feature is that the engineer has an eye on function and utility. Therefore, there may be a creative engineer versus a creative sculptor, painter, poet or musician" (p. 2).

Regarding the classroom environment itself, Amabile (1983) stated that when all the social and environmental factors that might influence creativity are considered, most can be found in the classroom. She categorized environmental factors into areas that included peer influence, teacher characteristics and behavior, and the physical classroom environment. Grouping of students in heterogeneous groups; having a teacher that is intrinsically motivated and believes in student autonomy and self directed work; and being in a cue-rich and therefore cognitively stimulating classroom were all examples of environmental factors influencing student creativity.

Although a variety of environmental variables have been identified that may influence creativity, *climate* is also an important consideration in the discussion (Hunter, Bedell, & Mumford, 2007). At the individual level, climate represents a cognitive interpretation of a situation and has been labeled *psychological climate* (PC) (James, James, & Ashe, 1990). PC theory supposes that individuals respond to cognitive representations of environments rather than to the actual environments (James & Sells, 1981). In essence, the climate of a classroom is a more global view of environmental influences on creativity. Most of the classroom research has focused on the distinction between "open" and traditional classrooms climates (Amabile, 1983, p. 205). *Openness* is most often considered a style of teaching that involves flexibility of space, student selected activities, richness of learning materials, combining of curriculum areas, and more individual or small-group than large-group instruction (Horwitz, 1979). In contrast, traditional classrooms consist of examinations, grading, an authoritative teacher, large group instruction, and a carefully prepared curriculum that is carried out with little variation (Ramey & Piper, 1974). As might be anticipated, most evidence regarding creativity favors open classrooms (Amabile, 1983).

A drawing of the ACS classroom and labs can be found below in Figure 1.

Figure 1: Drawing of the layout of the ACS program classroom and labs located within Benilde St. Margaret's School, St. Louis Park, Minnesota



Characteristics of an open classroom environment were evident in the facility and manner in which Jump and his students operated in the ACS classroom. Below, he describes how students take advantage of the energy the environment of the ACS program and classroom encourages.

Jump. If you look at our lab we have an Engineering I (10^{th} grade) lab and Engineering II and III (11^{th} and 12^{th}

> grade) lab and they are connected… open to each other. The Engineering II and III kids, the advanced kids, will go and pick on that at the same time will teach the young kids. The young kids will go over to the advanced side and see what they are doing and get inspired. So the open environment makes it very much a family, a team and not we're just in this classroom and just this one thing.

Theme 4: Teacher serves as a guide rather than the "sage".

Carroll (2000) commented that "the distinctions between 'teacher' and 'student' no longer serves us well. That is why I believe education is rapidly moving toward new learning environments that will have no teachers or students—just learners with different levels and areas of expertise collaboratively constructing new knowledge" (p. 126). Altan and Trombly (2001) offer learner-centeredness as a model for managing classroom challenges because of its capability of addressing diverse needs of students. Specifically, learner-centered classrooms, as the name implies, place students at the center of classroom organization and respect their learning needs, strategies, and styles. Carroll explains that this model is problematic because it places the teacher outside of the learning process. Rather, he suggests that the teacher acts as more of an "expert learner" among the students: "… the expert learner, the more senior, experienced learner, the person we pay to continue to structure these learning activities… is also constantly learning more and modeling the learning process, as opposed to the teaching process" (p.127).

The idea of Jump taking the form of an expert learner rather than the sole disseminator of knowledge is evident as he explains his approach to instruction.

> *Jump.* …it's that change (in students)… 'you mean I have to gain some responsibility here, I've got to come in and get to work so I can learn this stuff… not wait on

> somebody to just hand it to me…' They are just used to the teacher taking them day to day and however far the teacher gets it's how far they get.

Research Objective #3

Identify challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts.

Theme 1: Assessment of student learning.

Assessment of student learning is not only desired by educators in order to determine if their students have gained the knowledge they meant to impart, but it is often mandated by government (i.e. No Child Left Behind). However, Kimbell (1997) wrote "the assumption that it is possible to use small, clear discriminators as a means for assessment in design and technology is a snare and a delusion" (p. 37).

Historically, technology educators have chosen the creation of products or artifacts as a means to teach technological concepts (Knoll, 1997). Much of the new engineering design-focused curricula, including the curriculum used in the ACS program, is focused on open ended engineering design problems that yield an end product as a solution. Often this product is meant to embody the learning process students progressed through and, as a result, is used by teachers to assess the learning and creative work that has hopefully taken place. In essence, as Michael (2001) stated, it is this creative product that personifies the very essence of technology. However, neither a product nor a standardized test can always communicate the creative work involved in long-term tasks and multistage projects inherent in modern engineering oriented education.

Although he is about to complete a comprehensive curriculum he has developed for his Engineering 1 course that includes written and performance exams at regular intervals, Jump explained that assessment of student learning in the ACS environment has been and, at the Engineering 2 and 3 levels, continues to be challenging.

> *Jump.* So trying to figure out how to measure this was not easy… a lot of just trying to figure things out and how do you grade a kid when you don't know whether or not the tool you're using is effective at all… what's good in terms of documentation?... my goal is for you to be able to independently assess different products, different language forms, different micro controllers and make good selections, because at the high end that's what you have to do… that's very different then "here's the kit, just plug it all together."

Theme 2: Stakeholders uneasy with new pedegogy.

As Wagner (2001) observed, teachers are like craftspeople. The profession "attracts people who enjoy working alone and take great pride in developing a degree of expertise and perfecting products such as lessons, activities, and assessments. Wagner mentions that "most educators are risk-averse by temperament.... Most people have entered the teaching profession because it promises a high degree of order, security, and stability" (p. 378). Change unfortunately requires disagreement, conflict, anxiety, etc. The establishment of the ACS program did facilitate the disagreement, conflict, anxiety mentioned. Jump explains that fellow teachers as well as parents expressed concern for the approach the ACS program took to teaching science.

> *Jump.* Some of them (teachers) are a little older… are looking at you going "what are you doing, that's not the way we do things…" there were parent phone calls, what's he doing?, how come we're not doing this traditional process?… My kids have to take the SAT and get into college and how is this helping them do

> that? …So that was one of the things that my administrators dealt with.

Research Objective #4

Strategies used to overcome challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts.

Theme #1: Financial and instructional support through business partnership.

It has been established that there is a growing need for engineers in the U.S. (Clayton, 2005). Not surprisingly, the engineering community, including engineering professional societies, schools of engineering, and firms that depend heavily on engineering talent, have spent hundreds of millions of dollars annually on initiatives to raise the level of the public understanding of engineering (NAE, 2002). Regarding engineering education specifically, the benefits to businesses requiring novel thinking and technical savvy of future employees is clear. NAE (2009) outlines the potential benefits of K–12 engineering education:

- improved learning and achievement in science and mathematics;
- increased awareness of engineering and the work of engineers;
- understanding of and the ability to engage in engineering design;
- interest in pursuing engineering as a career; and
- increased technological literacy (pp 49-50).

Benilde-St. Margaret's is a private catholic school that relies heavily on donor support. Termed “Friends of Benilde-St. Margaret's”, these private donations can and are often made by local businesses. However, when Jump began the ACS program, his intention was not to campaign for specific funding. Rather, funding came to his program, or more accurately, because of his appraoch to teaching engineering during a chance encounter.

> *Jump.* Being a private school you have donors... come on over, let's show you the cool things we're doing... it was just a very informal thing, from my end, it was just oh people walked through the door, oh hi, how are you doing Mister So and So, nice to meet you. I had no idea they were coming.

One donor in particular was the CEO of a local engineering firm. Jump explained that he was intrigued not only by the approach the new ACS program took regarding the teaching of science and engineering concepts, but the degree to which it addressed his concerns about the lack of local talent.

> *Jump.* [the donor] really liked it and that's when this program started, because he challenged us. He said, "can you do more with this type of program, this type of learning?" …he already saw the need as someone that owned an engineering firm that we got to get more kids into engineering because all of our talent is starting to leave.

The financial support this particular donor offered allowed Jump and his ACS students the freedom to proceed in a way that was uninhibited by administrative concerns about program costs.

> *Jump.* …the first obstacle is always financially how do you build something like this… You go to the administration and say "well I want to do this thing and they're going to want to know what's it going to look like and what's it going to cost? We didn't have to worry about that because one of our donors gave us a challenge grant and said, can you build something?.. So

> I didn't have to politic and try and talk my administrators into doing this.

However, Jump explains that although financial freedom is important, the technical support and guidance offered by the donor was just as valuable.

> *Jump.* We're building big robots… we don't know what we are doing and we are partnered with [company name] Engineering… they are doing some design and working with the kids and we even created Engineering Friday's where those kids that only attended my class on Fridays that spring semester… we all spent the whole day over in their warehouse… it would have been impossible… because we had no tools. I didn't even have a screwdriver.

Theme #2: Administrative Support.

It should not be surprising that support generally leads to confidence and a subsequent feeling of freedom to take chances. For example, Wright and Custer (1998) found that along with a lack of understanding and support for technology education, teachers of the discipline indicated a lack of support funding for equipment, supplies, and facilities by administration as the most frustrating aspect of teaching technology education. Relative to support of teachers generally however, Newmann, Rutter, and Smith (1989) found that when school administrators offer teachers help, support, and recognition, they developed a heightened sense of unity and cooperation for the nature of their work.

Jump describes that the administration at Benilde St. Margaret's, fueled by the desire to both encourage a potential donor and confidence in his teaching ability, afforded him this degree of confidence and the resulting feeling of having some room to experiment while he developed the ACS program.

> *Jump.* …my administrators had a lot of confidence in what I was doing… courses based on these competitive projects, like what was happening with MIT at the time… [parents said] 'he doesn't send any homework home and his tests are all goofy and it doesn't look anything like what real school looks like.' So that was one of the things that my administrators dealt with.

Findings and Discussion

The purpose of this section is to summarize and then discuss the findings of this case study. Specifically, each finding will be presented and subsequently accompanied by a discussion of the effect on high school engineering education.

Finding #1: Teachers desiring to deliver engineering ideas via a naturalistically developed curriculum need to have a firm conceptual understanding of the content they aspire to deliver.

Throughout the interviews the researcher attempted to ask on several occasions what particular skills Jump and the ACS curriculum were able to deliver. When pressed, the teacher alluded to a CAD program, the ability to use certain automated tools to make custom parts for robots, and being able to manipulate LEGO pieces to achieve a certain task demanded of the modules he had authored. However, these references were few. Rather, unprompted Jump spoke often of the desire to have students understand not only specific concepts such as force, statics and dynamics, simple machines, torsion, cross bracing, material properties, programming, and electronics, but broad ideas such as problem solving, research, analysis, and design. At one point, the researcher asked Jump why he didn't spend more time teaching his students how to use the extensive machine tools in his classroom. He explained simply that they were all very unsafe, but more importantly, Jump indicated that this wasn't his goal. He needed to focus on what he felt was important that students learn in the short time he had with them:

> "It's like my goal is not to teach them how to be a machinist. My goal is to teach them how to problem solve… To me, [machining] a job specific skill. If I need to learn how to use this machinery for my job, I can learn it at the job, sort of that apprenticeship type of thing. I don't need that in high school… how much time do I have? I can't teach them everything."

As stated earlier, there is much interest in incorporating engineering education within technology education. Disturbingly, however, as demonstrated in *Technology for All Americans* (International Technology Education Association, 1996), the fact that a rationale and structure for the study of technology is presented is evidence that the issue of an agreed upon conceptual structure still remains unclear. However, since concepts such as design, engineering design, trouble shooting, and problem solving appear frequently in standards more recently written in 2000 for technology educators (International Technology Education Association, 2000), it seems that not only is this fog being lifted, but concepts related to engineering, much like what is being focused on in the ACS program being studied here, are appearing as a common theme. Certainly, it could be assumed that as these concepts are more clearly defined or at least universally agreed upon, that a concerted effort by teachers to explore novel ways of delivering these ideas can begin en masse. However, this type of curricular exploration, discovery, and development demands an open mind, a degree of ease with the unknown, and support. More on these types of traits will be outlined in the following findings.

Finding 2: Teachers wanting to develop an engineering program need to "think big".

As it was noted, the ACS program used available science and engineering competitions as a backdrop for activities designed to teach physical science and engineering design concepts. This approach is not new. Super mileage vehicle competitions (Thompson & Fitzgerald, 2006), the West Point Bridge Design Contest, FIRST Robotics Competition, FIRST LEGO League, and the Science Olympiad (Wanket, 2007) are all team based activities that are frequently mentioned in engineering and technology education literature for their ability to encourage students to work together to solve problems with specific technical parameters.

Unique to Jump's approach was a focus on competitions not only happening at universities that were considered *high church* relative to engineering education such as the Massachusetts Institute of Technology (MIT), but what was being publicized by the media through programs such as Scientific American Frontiers on the Public Broadcasting Service (PBS). He commented that in addition to adding to his own excitement about the content, these entities added a degree of importance and legitimacy to the work students were doing and his approach to the material.

In addition to setting the bar high by using exemplary university level activities to act as the basis for instruction, Jump leveraged engineering related reference materials published by the faculty at these institutions such as *Designing Engineers* by Louis L. Bucciarelli (1994) of MIT and *To Engineer Is Human: The Role of Failure in Successful Design* by Henry Petroski (1985) of Duke University. He commented that these books were tremendous resources in forming the platform for his naturalistic approach to developing the ACS curriculum:

> "…all these books came about in my exploration once we started this program. What is advanced competitive science? What is it that we are trying to do? We didn't do top down. I didn't start off with a set of objectives and we're going to meet those objectives."

Students of the ACS program that progressed to post secondary engineering programs were also rich sources of input to the program. This information helped Jump maintain a curriculum that was consistent, relevant, and contemporary. Said differently, he wanted to prepare students for what they would find in college:

> "Then as the kids were graduating getting feedback from the colleges. 'Oh this was great, I knew this and none of the other kids did' or 'you know we did that but that didn't help me at all.' So just allowing the feedback from the kids, what's working, what's not, then we can tweak the program and start really understanding what the colleges are looking for. What are the critical skill sets when the kids are going into engineering school that pay huge dividends for them versus the things that just weren't working that way."

Jump also discovered through developing his ACS curriculum that he had a tendency, shaped by years of being a teacher accustomed to tight program budgets, to allow the high cost of entering certain competitions or purchasing contemporary technology limit the program's potential. Because of the attention his approach to science and engineering garnered from local industry, financing became, in essence, a non-factor. Even so, he explained it was hard for him to grow accustomed to spending money:

> "So [a private donor] was excited about letting us experiment and supporting our experimentation. You know, gave me a credit card… like a $10,000 limit… I'm like what?!... [the donor said] don't worry about it,

> just get what you need… I come from a background where we've got $500 for the whole science department… just spend $10,000, I had no concept of how to spend this."

Finding 3: Teachers desiring to naturalistically create an engineering curriculum need to be at ease with the creative process and the ambiguity involved in learning new content and contemporary technology.

It was evident through interviews and observations that Jump was at ease with a certain degree of vagueness and uncertainty. The researcher often recorded him either saying to students or referencing instances that, because he didn't know the answer, resulted in a response of or related closely to, "I don't know. Let's find out."

Guilford (1950) identified an ability to evaluate, deal with complexity, reorganize, change one's mental set, possess a sensitivity to problems, and the capacity to produce many ideas as salient features of creative personalities. Although he was diligent in his pursuit of building the ASC program on novel ways of approaching science and engineering concepts, Jump repeatedly mentioned that the process was fraught with curricular, pedagogical, and technical trial and error. It was obvious that he was able to take this in stride rather than view it as a set back or a case of loosing face in front of students. It has been found that a teacher attempting to make such a curricular shift, like that required for successful implementation of engineering design activities offered in the ACS program, may feel uncomfortable because what they are being asked to teach is not reflected in their own educational experience (Anderson & Roth, 1989; Ball, 1996). As opposed to the disposition Jump displayed in this research, some teachers may view themselves as the only source of knowledge in the classroom. This can have serious implications in an environment that demands flexibility and an ability to deal with fresh problems that can arise (Ogle & Byers, 2000).

Finding 4: Administrative support for program development relies just as much on a teacher's record of solid instruction and demonstrated student learning as available financing.

Although Jump displayed the demeanor of a teacher that betrayed intellectual and managerial suppleness, he had established a history of success in student learning demonstrated through standardized assessment. Being that Benilde St. Margaret's is a private college preparatory school, it was imperative that its students were at least able to perform well on the entrance exams measuring competence in core subject areas, not the least of which include math and science. It is important to mention that there was no tenure safety net for teachers at Benilde. This could certainly be interpreted as a motivating force to apply to teachers to be held accountable for student learning. Jump clearly explains, "There is no tenure at this school… I could get fired today just like anybody else for lack of job performance. No tenure. No union… it's all job performance."

Additionally, it is important to note that Jump's ACS program is an elective and does not apply as a science or math credit. Therefore, the obvious pressure to support the college preparatory ethos of the school and population the ACS program serves is palpable. The program has produced results. Jump explained.

> "I think the proof started coming in with these kids as they moved through, were doing better in their physics classes, better in their math classes, because that was something we started to get a reverberation of… So the administrators liked what I was doing and saw the benefit and were getting a lot of positive feedback from the parents."

It has been suggested that if teachers are to be successful when venturing into new realms such as the ACS program, they must have both strong pedagogical and content knowledge to remain comfortable in their classrooms (Tobin & Fraser, 1990). It would appear that the degree to which a teacher understands their school's core curricular aims and can deliver an engineering content that is in alignment with and sensitive to these would serve to indicate the success of such a program.

Conclusion

Teachers interested in creating and delivering engineering curriculum naturalistically need to begin the process with clear thinking about the conceptual framework they need to deliver to students. The nature of open-ended problems, which are being suggested as the richest way to deliver such a curriculum, defy attempts to assemble a reliable list of skills needed. This is not to suggest valuable skills will not be developed along the way to assembling novel solutions to real world scenarios suggested. Rather, as opposed to a curriculum that attempts to develop students' understanding of all engineering concepts, pains should be taken to focus on a thorough treatment of a particular concept. By teaching through this lens and allowing time for students to wrestle with iterative nature of open-ended problems, a deeper, more meaningful and transparent understandings can occur.

Second, teaching strategies rely on the teacher's comfort with their ability to adapt to ambiguous and novel situations that occur within open-ended problem solving which are characteristic of effective engineering curricula. Support and validation for such an approach can be gained by utilizing activities and challenges offered by the institutions and organizations that represent the best thinking in the field.

Additionally, reference materials should be compiled from these same sources to act as a daily reference for engineering teachers. It is important to note that these resources may vary per the learning style and prior knowledge of each individual.

Lastly, by establishing administrative and industry support, obstacles to successfully developing and implementing a naturalistically developed engineering curriculum can be addressed. Administrative support can be garnered by a teacher's record of student learning per the goals of the school curricula. This can be accomplished by a teacher's pointed efforts to first offer a curriculum that features powerful learning activities that are underpinned by the teacher's articulated understanding of the concepts they were built to teach. Next, involvement of local business and industry in department and school advisory committee functions, school and district open houses, volunteer, and guest speaker opportunities not only demonstrate a teacher's intrinsic motivation, but also showcase vision that extends outside the school building. These efforts can generate an idea and sensory rich environment for potential supporters to experience the energy that often characterizes engineering work.

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High School Engineering and Technology Education Integration through Design Challenges

Nathan Mentzer
Purdue University

Abstract

This study contextualized the use of the engineering design process by providing descriptions of how each element in a design process was integrated in an eleventh grade industry and engineering systems course. The guiding research question for this inquiry was: How do students engage in the engineering design process in a course where technology and engineering intersect? Data to address this question were collected during six weeks of observation and discussions with students at a suburban high school of 1500 students. Additional data were obtained from student and teacher generated documents, such as lesson plans, handouts, student journals, reports and presentations.

This study assumed six critical elements of engineering design: problem definition, development of solutions, analysis/modeling, experimentation, decision making and teamwork. These six elements of an iterative process were derived from a review of engineering design literature and became a lens through which the classroom learning experiences were viewed.

Nathan Mentzer, is an Assistant Professor in the Technology Leadership and Innovation Department at Purdue University. He can be reached at nmentzer@purdue.edu.

Evident in the observations was the theme of student transition from teacher driven problems with narrow boundaries, to student driven problem definition with wide boundaries. In this research, projects started as small individual activities early in the fall term. As the semester progressed, projects became more complex, and a necessity for teamwork emerged. Each activity in the fall provided students with experience and skills in areas of engineering design and material fabrication. This preparation provided a conceptual and practical foundation for the open-ended spring design challenge.

Introduction

Technological literacy is an important educational goal for all high school students (International Technology Education Association, 2000). Scholars in technology education and engineering disciplines, as well as the general public, have expressed the need for technological literacy and asserted that our K-12 educational system must address the issue (Gamire & Pearson, 2006; Gorham, 2002; International Technology Education Association, 1996, 2000; Pearson & Young, 2002). The impacts of decisions related to technologies are complex; the ability to make thoughtful decisions regarding the relationship between society and technology is essential for our nation's continued economic prosperity (Pearson & Young, 2002).

Though a need for a technologically literate citizenry is evident, many people do not possess the literacy to make informed decisions about technology. The ability for consumers, as well as business and political leaders, to weigh the impacts and implications of their decisions regarding the use and development of technologies is essential but currently insufficient (Pearson & Young, 2002).

Engineering and engineering design are included in *Standards for Technological Literacy* (International Technology Education Association, 2000). Including engineering content in technology education curricula demands the field identify opportunities and approaches to teaching engineering at the high school level. Engineering design challenges include the application of engineering principles to solve real-world problems with an active, hands-on methodology. Incorporating engineering design challenges in formal coursework is one approach to teaching the engineering process through practical application. “In brief, available research suggests that these kinds of courses appear to improve retention, student satisfaction, diversity, and student learning” (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 114).

Purpose of the Study

The purpose of this case study was to identify evidence of the engineering design process in a high school technology education classroom using naturalistic inquiry. The guiding research question for this inquiry was: How do students engage in the engineering design process in courses where technology and engineering intersect? Data to address this question were collected during six weeks of observation and discussion with students at a suburban high school of 1500 students. Field notes were compiled by the author during five extended visits spanning an academic year. Additional data were obtained from student and teacher generated documents, such as lesson plans, handouts, student journals, reports and presentations. The fall semester provided students with a series of small structured design challenges to contextualize engineering concepts in hands-on activities and to prepare them to approach an open ended large scale design project during the spring semester.

Technological Literacy Includes an Understanding of Engineering

The role of engineering in developing technological literacy was established in the *Standards for Technological Literacy*. The International Technology and Engineering Educators Association has identified 20 standards for facilitating the development of technological literacy. Standard number nine reads, "Students will develop an understanding of engineering design" (International Technology Education Association, 2000, p. 210). Gorham and colleagues (2003) described a synergistic relationship between engineering and technology education toward a common goal of technological literacy, suggesting that the *Engineering Criteria 2000* (Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology Inc., 2001) and *Standards for Technological Literacy* show "clear connections" (p. 97).

As suggested by Hailey, Erekson, Becker, and Thomas (2005), "The design process described in [the *Standards for Technological Literacy*] Standard 8 is very similar to the introductory engineering design process described in freshman engineering design texts with two notable exceptions" (p. 24).

> The first highlighted difference shows the role of analysis in introductory engineering design compared with Standard 8, which prescribes selecting an approach, making a model or prototype, and testing the approach. Engineering programs teach analysis as the decision making tool for evaluating a set of design alternatives, where 'analysis' means the analytical solution of a problem using mathematics and principles of science.
>
> The second highlighted difference shows the importance of creating or making the designs, as

> prescribed by Standard 8, in contrast with the introductory engineering design process, which prescribes that students develop 'design specifications' so someone can create the design, not necessarily the engineer or engineering student. (pp. 24-25)

Lewis (2005) suggested that one method of integrating engineering and technology education is through the use of design challenges. This recommendation corroborated the position of Gorham, Newberry, and Bickart (2003), who held that a synergistic relationship is evident between the fields. Technology educators often pose design challenges to students in their classes. As students progress through the technology education design model, the addition of analysis to this procedure might facilitate the integration of engineering design. Lewis commented:

> Design appropriate for technology education is characterized by open-ended problems where the designer bridges the gap between past experiences and the current problem to be solved; one method of achieving this transition is through engineering design challenges. (p. 49)

Characteristics of Engineering Design

Design is recognized as the critical element of engineering thinking which differentiates engineering from other problem solving approaches (Dym, 1999). The definition of engineering design has been established by the Accreditation Board for Engineering and Technology (ABET) (2007):

> Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering

> sciences are applied to convert resources optimally to meet these stated needs. (p. 21)

Smith (2000) surveyed the teaching of engineering design to first and second year students in a reflective column in the *Journal of Engineering Education*. Smith highlighted several texts which articulate engineering design on a level appropriate for early design experiences. *Introduction to Engineering Design*, by Eide, Jenison, Mashaw, and Northup (2001) was among the noteworthy texts. It is generally congruent with other introductory college level texts describing the engineering design process for engineering students (Dym & Little, 2004; Eide, Jenison, Mashaw, & Northup, 1998; Eide, Jenison, Northup, & Mickelson, 2008; Moore, Atman, Bursic, Shuman, & Gottfried, 1995). Table 1 displays the design process as synthesized from the literature and employed in the current study. The six main elements are described generally as follows:

Problem Definition. Problem definition includes addressing well-defined and ill-defined questions, as stated by Dym and others (2005):

> No sooner has a client or professor defined a series of objectives for a designed artifact than the designers–whether in a real design studio or in a classroom–want to know what the client really wants. What is a safe product? What do you mean cheap? How do you define the best? (p. 104)

As part of defining the problem, a clear view of the need must be articulated in association with identifying the constraints governing the problem. This clear view of the problem and its boundaries is well articulated in the literature and these two design models.

Solutions. Multiple solutions are identified through two intertwined approaches: researching existing solutions and brainstorming alternative solutions. Strong design teams gather information from multiple sources, judge its quality, and document their efforts (Davis, Gentili, Trevisan, & Calkins, 2002).

Table 1
Synthesis of Key Elements of Engineering Design

Element	Characteristics
Problem definition	Questioning Constraints Component/system level Evaluation criteria
Solutions	Research existing Brainstorm alternative
Analysis/modeling	Prediction Uncertainty Estimation
Experimentation	Empirical data gathering Based on analysis Prototyping
Decision making	Evaluation of potential solutions Optimizing
Teamwork	Working effectively on teams Communications

Analysis/Modeling. "Mathematical or analytical models used to express some aspect of an artifact's function or behavior, where the behavior is in turn often derived from some physical principle(s)" (Dym, et al., 2005, p. 108). This analysis should consider technical, financial, system, life-cycle, and potential failure (Davis, et al., 2002). Modeling approaches are limited and incomplete at times, and, therefore, statistical tools should be considered to further understanding of the phenomenon. Estimation may be used since systems are complex, and modeling every aspect of the behavior is not always practical (Dym, et al., 2005, p. 106).

Experimentation. Experimentation is guided by analysis and modeling for purposes of validating the model and providing empirical evidence where data is insufficient. "The design of systems is rarely accomplished exclusively by applying fundamental scientific principles. In most cases, the design of systems also requires some use of empirical data and experimentation" (Dym, et al., 2005, p. 106). An interactive relationship between experimentation and modeling serves to guide the development of understanding and design progression (Box & Liu, 1999).

Decision Making. "[D]esign is a rational process of choosing among alternatives" (Dym, et al., 2005, p. 107). A decision matrix helps assist students in objectively considering the alternatives based on their advantages and disadvantages (Gomez, Oaks, & Leone, 2004). Quality design decisions involve full team participation and consensus, and an optimized solution based on iteration and refinement (Davis, et al., 2002).

Teamwork/Communications. ABET criterion 3(d) articulated a need for students to function on a multidisciplinary team. "[B]oth cornerstone and capstone project based courses are seen as opportunities to improve students' ability to work in teams, as well as their communication skills" (Dym, et al., 2005, p. 107). Good teams exhibit characteristics such as clear purpose, defined roles and responsibilities, inspiring climate and attitude, effective resource management, and an incentive implementation plan (Davis, et al., 2002). An essential component of design team success is communications. "Different languages are employed to represent engineering and design knowledge at different times, and the same knowledge is often cast into different forms or languages to serve different purposes" (Dym, et al., 2005, p. 108). Dym further suggested multiple communication mediums which include verbal, graphical, mathematical or analytical models, and numerical.

Methods

Qualitative case study methodology was employed in this study. As described by Gall, Gall and Borg, "A case study is conduced to shed light on a particular phenomenon, that is, a set of processes, events, individuals, or other things of interest to the researchers" (2005, p. 308). In order to most effectively establish this rapport, six weeks of site visits were conducted during the school year. Gaining entry to the research site means study participants forget a researcher is present and "let down their guard" (Gans, 1968). After entry had been gained, observations were conducted. Documents were gathered including lesson plans, student handouts, and student generated materials. These documents and observations served to present a comprehensive description of the research site, including the teaching methodologies employed, and the delivery of specific content.

Analysis strategies included a general review of all information, feedback from informants, data reduction, and categorization. Data analysis was conducted as conceptualized by Creswell (1998) as a "spiral" (p. 143). Data collection led to data management, reading and memoing, describing, classifying and interpreting and finally representing. This iterative process evolved as the study progressed thus shaping the data collection and being shaped by data which were collected and interpreted.

Data collection included journaling observations during lectures and labs where the researcher was seated in a student desk near the back corner of the classroom. The researcher took an active role in moving among groups of students as they worked on projects in the lab settings. Quotes, as well as observations, were documented. The researcher regularly asked the students what they were doing and why, probing for a verbalized explanation in student language. Care was taken to minimize leading questions from the dialog, and limit interactions to what became typical questions, "how and why." Students grew accustomed to this regular inquiry and would anticipate the questions before the researcher would ask. This regular dialog became a natural interaction between the researcher and students.

Documents were collected from the students and teachers. All students were required by their instructors to complete a journal as a part of their daily routine. As students completed assignments, they would submit a report for evaluation to the instructors. This report included their daily journal, student data collected, analysis completed (typically in the form of a worksheet) and written reflective components in which students were asked to describe the process and what they could have improved for next time. All data were reviewed multiple times to prepare for classifying. Data categorization followed a constant comparative strategy as outlined by Bogdan and Biklen (1982), Stainback and Stainback (1988), and Taylor and Bogdan (1998). This strategy involved a six-step methodology wherein categories were created by important issues or recurring events. Additional data were collected to provide many examples for each category. Data coding and themes generation were, in part, established a priori to parallel the six elements of engineering design for this study (found in Table 1). Theme generation was not limited to these six elements; as data were reviewed additional emergent themes were discovered in the analysis process. Patterns and relationships were identified and additional data collection served to refine findings.

Verification

"Qualitative researchers strive for 'understanding,' that deep structure of knowledge that comes from visiting personally with informants, spending extensive time in the field, and probing to obtain detailed meanings" (Creswell, 1998, p. 193). Verification that data were collected and interpreted appropriately was critical to the quality of this study. As Eisner (1991) suggested, "We seek a confluence of evidence that breeds credibility, that allows us to feel confidence about our observations, interpretations, and conclusions" (p. 110).

Multiple procedures of verification were followed in this study. Creswell (1998) suggested engaging in a minimum of two verification procedures. For purposes of verification in this study, the researcher has utilized five procedures: prolonged engagement in the field; triangulation; clarifying researcher bias; member checks; and rich, thick description. The researcher has made five site visits, four of which spanned a total of six weeks and included observation of the interactions between the participating teachers and their students. This extended series of observations provided the researcher with data saturation and ensured multiple observations for each theme established. Triangulation was addressed through connecting gathered observations, student generated documents, teacher generated documents, and informal interviews with 53 students in two sections of the participating classes. Researcher bias was briefly presented in the findings section prior to describing the results so that the reader may understand how the researcher's background might influence the interpretation and approach. Member checks were conducted through formal meetings with the participating instructors scheduled during each of the four observational visits. The entire qualitative findings section was presented to the participating teachers for feedback and corrections. Lincoln and Guba (1985), consider member checking to be "the most critical technique for establishing credibility" (p. 314). Rich, thick descriptions are presented in the results section which "…allows the reader to make decisions regarding transferability" (Creswell, 1998, p. 203).

The Research Setting

Site selection criteria included a clear emphasis on infusing engineering concepts into a traditional technology education classroom and a diverse group of learners. A high school classroom was identified in which a physics teacher and a technology education teacher worked as a team to infuse and apply engineering concepts in a course called "Industry and Engineering Systems." This eleventh grade course included an academically diverse array of students. During the fall term, students participated in hands-on learning experiences which represented an intersection of technology education and applied physics, for example; concepts such as motion, forces, electricity, magnetism and simple machines, as well as welding, machining, mechanical fasteners, cutting and bending metals. During the spring term, students applied these concepts in design teams to the Electrathon America challenge, a semester long engineering design challenge. The spring term culminated with fabrication, testing, and redesign of the student designed and built electric cars.

Classroom lectures, activities and lessons modeled infusion of engineering concepts into a technology education classroom. Typical technology education projects during the fall term included magnetic levitation cars, Lego/solar cars, gearing systems, and electric motors. These projects facilitated the marriage of practical applications with engineering design. The instructors' classroom goals included encouraging the students to see the application of math, science, and language arts to hands-on projects and basic engineering concepts.

During the fall semester, teachers concentrated on providing a foundational knowledge base for the spring term. In early January, students started the engineering design challenge with a 1/10th scale model of an electric car and driver. Teams of 2-6 students designed, modeled, and built their Electrathon vehicles. Constraints were imposed by the Electrathon rule book and local facilities. Designs were optimized for weight, balance, tire scrub, air resistance, and other characteristics. Predictive analysis was incorporated into the modeling in the form of model car wind tunnel testing, gear ratio calculation, power demand calculation, and ratios of speed and battery life to distance traveled. Understanding of these parameters was developed in the fall term by building and testing smaller projects such as magnetic levitation cars and calculating horsepower capacity of a student built electric motor.

To insure anonymity, pseudonyms were used to identify the participating teachers, district, and students. Mr. Brewer has been designing, building and racing vehicles with students for 14 years while Mr. Rivet has been teaching for 10 years. Mr. Brewer and Mr. Rivet had 53 students enrolled in the Industry and Engineering Systems courses in which they teach students to think, problem solve, and work as teams to design, build, modify, maintain, and race an Electrathon vehicle. Mr. Brewer is a certified teacher in physics, math and chemistry. Mr. Rivet is a certified career and technical education teacher endorsed in manufacturing technology. They teach courses at Porter Valley High School, which serves approximately 1,500 students in grades 9-12.

Results

Researcher bias is inevitable in presenting qualitative data. The researcher in this study was a former high school technology education teacher with five years experience and adhered to high expectations of students. The researcher had a personal interest in engineering and felt that engineering design could be successfully integrated into technology education curriculum. With this bias presented, the following qualitative data represents a description of what students were encouraged to accomplish during a fall and spring semester at Porter Valley High School. Student quotes, teacher quotes and observations triangulate a common message: Engineering design elements were being applied by the students.

Data were collected on the teaching practices which shaped the learning environment in the form of observations, documents, and curricular plans. Qualitative data collected portray evidence that engineering design was a major focus of this course and that students were practicing these elements of engineering design. Additionally, these data serve to demonstrate a model for infusing engineering design into technology education.

Students who participated in this study enrolled in two co-requisite courses. The courses were scheduled together, facilitating the use of a larger block of time as needed. The fall semester and spring semester were formatted differently based on the goals and educational approaches utilized. During the fall term, the courses were distinctly independent, and the instructors acted in relative isolation from each other. One instructor focused on metal fabrication techniques, and the other instructor focused on teaching engineering as applied physics through a hands-on design based format. The concluding projects for each course in the fall term set the stage for design and fabrication of the engineering design challenge that officially began with the spring term when both classes were fully integrated.

Six main units of instruction were used in teaching engineering design during the fall term. These six units included magnetic levitation, electric motors, solar power, gearing, and two scale modeling experiences. Data were gathered to demonstrate the teacher and student interaction with these six elements. Examples of students' work are presented in combination with classroom observations.

Problem Definition

Throughout the fall term, students were presented a variety of challenges. The responsibility for defining the problem transitioned from a heavily teacher defined problem to a student defined problem as the semester progressed. An excerpt from Jerome's journal on the first assignment matched the instructor's handout almost verbatim, "Our project was to design and construct [a] maglev car with propeller propulsion that will be balanced [and] stable. And race the full length of a 16 foot track in the shortest amount of time." Another student commented on the first assignment that she recognized aerodynamics are a key subcomponent of the actual problem at hand, "The first thoughts I had on doing this project were on how I was going to be able to make my car aerodynamic." Though she commented on aerodynamics, she was still following the instructor's problem definition as it included a requirement for a fast vehicle.

As the semester progressed, students introduced their own constraints in addition to the teachers' constraints. Near the end of the fall semester, students were assigned a design problem of creating a 1/10 scale model as a prototype for their electric car. One constraint they faced was an ergonomic accommodation of the driver. In Cori's words, "So to start it off we began by taking all of our needed measurements of our driver. This would allow us to build the frame and body of the car around that of our driver's body." Cori's comments described Figure 1, which showed data gathered by a student team on their driver's dimensions. This constraining factor was of consideration as it interacted with aerodynamics and physical size restrictions for the cars.

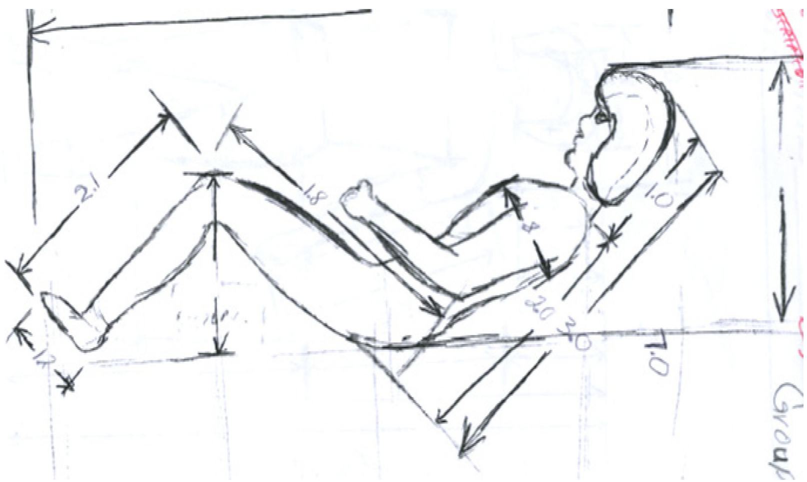

Figure 1. One-tenth scale driver sketch with dimensions

Evidence of evaluation criteria were produced by the instructors and the students. During the first few projects, students were presented with a rubric sheet that included 5-10 areas on which their project would be evaluated. This was a teacher generated form presented with the project briefing. Johan stated in his journal, "We tested the 5 minute run time. Our motor exceed the 5 minutes and ran for 15 minutes plus." In this instance, the student group had set a more stringent goal than had the instructor, but evaluation criteria followed the same testing procedures. Johan followed up with, "We were really proud!"

Solutions

Students were expected to develop multiple potential solutions to their challenges. These solutions evolved from research of existing solutions and brainstorming alternative solutions. As written by Johan, “When we started our project, we look at the examples and tried to see how we could perfect it.” The instructors provided examples of previous student work and often presented a critique of a few examples during lecture, most examples were marginally functional and facilitated a focus on opportunities for improvement. Students were encouraged to brainstorm and expected to document, with sketches, the various ideas developed. Evidence of the brainstorming sessions was a required component of student journals and included in the final report which accompanied the project for a grade. Students were expected to report details describing their solutions. Cori, a very articulate student, commented:

> I figured I would have to carve out the body to make a chamber for the air to go through so the propeller would have more wind hitting it. The next thing I thought about was how to raise the motor up. I decided to use slightly thicker pieces of foam so that they were more stable and have the edged rounded so that it would add to the aerodynamics of my car.

Analysis/Modeling

Students conducted analysis in a variety of activities. Students learned about gear ratios and practiced calculations of motor rotations per minute and wheel rotations per minute given a certain gear ratio. They were expected to be able to calculate gear ratios based on a given sprocket’s number of teeth and a pulley’s diameter. They also worked through calculations to determine the velocity of a car, given a gear ratio, motor RPM and wheel diameter. Students began to articulate connections between variables governing velocity of their moving projects. Johan stated: "In all, I found that the less friction and less wind resistance, the better your car will go down the track, and the faster it will move." This realization that specific variables govern the physical behavior of our world was a key component of this course according to the instructors.

Students made calculations of power based on the voltage and amperage generated by a pair of solar panels. They practiced calculating power to discover the power produced by a series circuit and a parallel circuit should be the same while the voltage and amperage vary inversely. Students also gathered data on solar power wattage based on distance to a light source. Students took six measurements, calculated power and tabulated the data. An example of Chinelo's data is shown in Table 2.

Table 2
Chinelo's Solar Power Data Based on Distance to Light Source

Distance (inches)	Voltage (volts)	Current (amps)	Power (watts)
0	2.35	.55	1.245
3	2.82	.31	0.626
6	1.94	.265	0.680
9	1.85	.24	0.444
12	1.81	.24	0.316
24	1.74	.06	0.123

Note. Data gathered from student worksheet

This example has a few multiplication errors in calculating wattage; however, the plot of distance and power (refer to Figure 2) appropriately resembles an exponential curve.

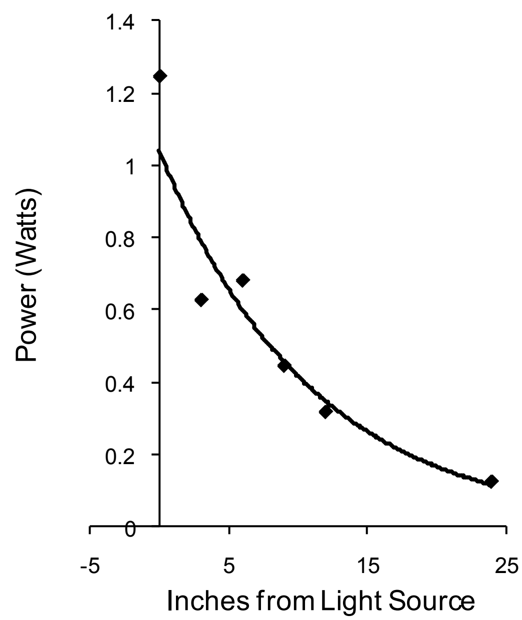

Figure 2. Digital representation of student hand drawn plot

Using this data analysis, students were asked to estimate the power at a distance they had not measured. Chinelo predicted, based on his curve, the power at 20 inches from the source would be approximately 0.159 watts.

As a component of learning analysis, students encountered inconsistencies in data collection. Students attempted to deal with uncertainty in measurement and performance by taking multiple measurements and calculating averages. The researcher observed teams talking about outliers (though not using this term) when referring to measurements that were dramatically higher or lower than other data collected. Typically, students noticed outliers when they inadvertently started a timer too early or too late in comparison to other trials. They used the average speed or times in their calculations. This allowed teams to compare their data to other groups with more confidence that their measurements (and calculations based on these measurements) represented reality.

Experimentation

Each unit of instruction had some element of experimentation. Experimentation was guided by considering variables governing physical behavior of the problem at hand. Students gathered data and prototyped a solution to each challenge. In Cori's words, "Today we listened to [Mr. Brewer] explain how to use the multi-meter. Then, we went and started finding the volts, amps, and watts that the four different solar panels had." This journal excerpt reflected on gathering data as a measurement of power based on the distance the solar panel was to the light source. In a following activity, students created a winch powered by the solar panels and lifted small weights. By measuring the amount of weight and time to lift to a specific height, students could compute a horsepower calculation based on a series or parallel circuit. Cori explained:

> Today [Mr. Brewer] explained more on how to setup the gearing to test which type of circuit is better in providing more horsepower. Then Asmara and I got to test our system. We also took and did 3 trials of each of the three types of circuits to get a more accurate timing.

Following the theme of power calculation, students designed and fabricated an electric motor (refer to Figure 3).

In this challenge, students refined their design based on data gathered

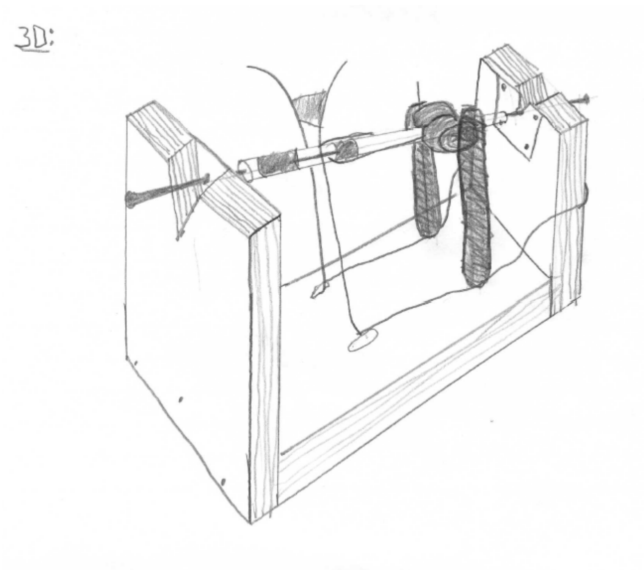

Figure 3. Student sketch of electric motor design

on horsepower. A string was wrapped around the armature and used as a winch to lift weight. Using the same technique as the solar power calculations, students analyzed the horsepower output of their motor and made changes to increase performance. Jovan commented on the iterative process:

> My second problem was, I couldn't get my brushes to work. This problem came with baggage. My coils weren't wired the right way and then I had to make my brushes to where they wouldn't short but also have contact for as long as possible. I fixed it by kinking my brush to a point and having it lightly touch the commutators.

Jovan articulated in his report that the experimentation he was conducting tied to an understanding that the magnetic fields caused motion (and power) in the motor. The longer the brushes contacted the commutators, the more powerful his motor. He recognized a tradeoff in the increased contact time with the commutators and the increased potential of a short circuit (if overlap occurred).

Decision Making

Students were presented with opportunities to make many decisions throughout the fall semester. Observational evidence suggested that students used sketching and conversation to discuss alternative solutions. When students were working in teams, they discussed ideas and often, concurrently, attached value judgments. While students were encouraged to separate brainstorming from decision making, students regularly engaged in the two activities simultaneously. In addition, students reflected on their decisions when asked how solutions could be improved. Cori stated in a reflection of the 1/10 scale model:

> Some of the ideas I have to make our full size car better, that were not considered while making the 1/10 scale car is to have the foot pedal instead of a thumb throttle. Some advantages to a foot throttle are in having a more familiar feel in the driving of the car. The second reason that this would be preferable is that there are frequently problems with the thumb throttles jamming or breaking during a race, taking lots of valuable time to fix. One disadvantage of this however is that it would limit the height of the people that we could have drive our car.

In this excerpt from her final report, one decision considered alternatives with advantages and disadvantages.

Students documented decisions they made in a similar fashion highlighting choices and identifying positive and negative attributes in order to make an informed decision. Dante reflected on decisions he made on a magnetic levitation car, "I learned here that making it look cool doesn't make it move[,] so for the Electrathon vehicle in the spring, I will make it simple but with all the necessary components made right for functionality."

Quantitative data were also used to drive decision making. Students used calculations of horsepower to assess changes in their electric motor designs and determine how to wire the solar panels. In brainstorming and preparing a design for the 1/10 scale model car, students gathered quantitative data on driver size (discussed earlier). These data served to constrain decisions on how the driver would comfortably fit into the car when designing the 1/10 scale model. Jovan provided evidence that he used quantitative information presented in lecture to drive the decision making process during the design of the electric motor. Jovan noted a relationship between magnetic strength and distance in his electric motor design, "I want to have my armature to clear my field magnets barely. [Mr. Brewer] said if it's twice the distance it only retains 1/4 of the magnetivity [magnet strength]."

Teamwork

Teamwork was a critical aspect of this course. Students started the semester with a project in which they worked as individuals, but as the semester progressed, nearly all activities required students to participate in teams. This progression from individual to small groups (then larger groups) allowed students to practice their communication and leadership skills. Students were presented with information on team dynamics such as how to select team members, leadership and group responsibilities. One of the student handouts suggested students consider team members carefully, “As with all team selections you may want to have a member with different skills than you so that they can help complete various tasks.” The team leader, “…should be able to delegate tasks well, not try to do it by themselves.” As the semester progressed, team members gained autonomy in their work habits. Early in the semester, each team member was involved with nearly all aspects of the project, but as the semester progressed, team member specialization and autonomy emerged. Students were expected to discuss plans and divide responsibilities to complete the jobs as suggested in a handout, “The team leader will compile a list of the members of the team and each person will chose one or more tasks on the car that they will be in charge of.”

Students had formal team meetings where a leader facilitated progress, a recorder compiled notes on brainstorming, plans and delegation of responsibilities. Cori, her team’s leader, documented, “I was the one who measured out and did configurations on the foam. Asmara would then cut out the pieces that I measured and Cédrick would do a fantastic job of sanding them down.”

Communication was an important element of teamwork and was used in various forms. Student sketches were a required part of the journaling and reporting process. In Figure 4, Jenson, Joseph, and Jace finalized their sketch for the 1/10 scale model car. This form of visual communication was commonplace among the students as was verbal communication in team meetings. Teams had daily meetings at the beginning and end of each period to plan the coming workload and distribute responsibilities. At the conclusion of each unit of instruction, students create final reports reflecting on their progress, what they learned and what they could have done better for next time. Cori's report on the 1/10 scale model illustrates her written reflection:

> There were several things that I learned during this project. The first was that I got better at welding on small things. I could make decent welds on larger objects before I started that car, and now I am able to do decent welds on smaller items. The second skill I acquired was in being able to work with fiberglass. This was something I had never done before and found that I am fairly good at it. A third skill I improved on was being able to take real measurements and put them into a working model.

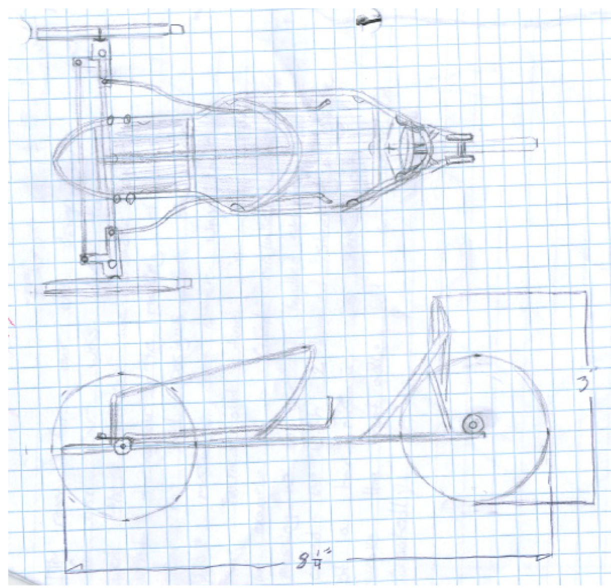

Figure 4. Sketching as a form of team communication

Emergent Themes

Two strong emergent themes developed throughout the term and were interwoven into each learning experience. One was the intense focus on preparation for the large spring design challenge. The other emergent theme was a transition from well-defined problems to ill-defined, and was increasingly open-ended as the semester progressed.

The focus in the fall on preparation for the spring challenge was discussed with the students and observed by the researcher. Each activity in the fall connected to some aspect of designing, fabricating, and learning to work as a team. Students learned to weld and practiced cutting, bending, and mechanically fastening metal in methods that could be used in layout and construction of the electric car. Students practiced on the same metal thickness and welding positions that would be directly transferable to the spring challenge.

Aerodynamics of the magnetic levitation car directly transferred to their electric car body with an intermediate step learning about fiberglass plug-mold technologies through their 1/10 scale model car design. Analysis of gear ratios and calculating speed based on motor rpm during their solar car activity transferred to the larger wheels in their spring challenge. The realization that theoretically gearing the car to go faster may actually make the car go slower (as the motor stalls) was a real experience in optimizing the gear ratio of the solar car and winch.

Team size gradually increased in preparation for teams of up to six students in the spring. Thus, leadership and participation were practiced before the spring challenge. While the rules for the spring challenge were well-defined, they focused primarily on safety and fair competition. Car design was largely an open-ended and ill-defined problem. As the fall semester progressed, students experienced an increase in their responsibility to determine the problem definition and evaluation criteria.

One of the capstone fall projects included a 1/10 scale model car, designed, and fabricated from steel frame members. Teams made fully articulated scale driver models to ensure the frame design fit their driver. Wheels and steering linkage were functional. Moving the steering wheel (or levers, as the case may be) moved 1/10 scale tie-rods which moved steering wheels. Mockup batteries and motors were in place to demonstrate fit and consideration of weight and balance issues.

The other capstone fall project was a miniature frame welded from full size material. The fixtures required to produce this frame project were mounted on a small section of plywood, laid out just as the full size car would be a few weeks later. Students discovered the challenges associated with cutting and fabricating steel tube and flat stock at predetermined angles. The instructor provided some of the dimensions as constraints and allowed students to design other aspects of the frame. The required dimensions forced student teams to figure out how to measure their material and develop fixtures to match specifications. This learning experience transferred to the full size car project as their design specifications were laid on a larger plywood board, and angles were critical for steering and the squareness of the frame.

Early projects in the semester were clearly defined and had focused evaluation criteria determined by the instructors. Design briefs listed evaluation criteria for the students to follow. The magnetic levitation design brief stated, "Design and construct a maglev car with a propeller propulsion that will be balanced, stable, and race the full length of a 16 foot track in the shortest amount of time." Students were provided with a list of constraints and materials available. In another early activity, students designed an electric motor. Their design had some freedom, but a 19-step assembly method narrowed the list of potential solutions. Each motor looked different and, in particular, students' designs for the brushes varied. However, in later assignments, a much greater degree of freedom was promoted, thereby expanding the problem and solution space with ill-defined problems.

As the capstone fall project, the 1/10 scale model provided students with many opportunities to address the problem creatively. The design was required to be scaled and, potentially, a car the team might want to build in the spring. Decisions on steering, weight distribution, driver position, frame, and roll bar design were entirely up to the students. This ill-defined problem yielded many unique and differing solutions. Students' problem definitions varied from rider comfort as a priority to aerodynamics as a higher priority, evident in the rider position from recumbent to upright. Ergonomics and aerodynamics are examples of design considerations (at times conflicting), but additional considerations such as safety, impact resistance, durability, and weight were in students' dialogs.

Discussion

Kindergarten through twelfth grade education has been identified as an opportunity to foster a technologically literate society (Gamire & Pearson, 2006; Gorham, 2002; International Technology Education Association, 1996, 2000; Pearson & Young, 2002). To be technologically literate includes developing an understanding of the engineering design process (International Technology Education Association, 2000). Engineering design challenges may be a way to bridge the divide between technology education and engineering as they provide an opportunity to focus efforts on a design project while applying engineering principles.

Results of this research suggest that students and teachers were engaged in applying an engineering design process in a technology education context. Hailey et al. (2005), identified analysis as the missing element in the technology education design process in a comparison with the engineering design process. This research suggested that students were conducting analysis in this classroom. This analysis was contextualized in a hand-on environment using traditional technology education experiences. Designing and building electric motors, for example, is not new to the field, but these students were expected to analyze mechanical power of the motor, calculate electrical consumption. In doing so, they developed measurement skills and made mathematical calculations. Their motors were optimized for performance based on experimentation guided by an understanding of pertinent variables.

Technology education has a successful track record in providing hands on experiences, but may strengthen its ties to an integrative STEM education approach by leveraging natural connections that exist. Performance of the electric motor (again as an example) is contingent on many variables including magnetic strength, friction, and electrical conductivity of the brushes. Scientific and mathematical thinking was applied in this context, potentially strengthening student learning of STEM concepts. The engineering design process often stops short of a building or construction experience. Technology education leverages historic strengths in the element of building and testing. An integration of technology and engineering in this research provided evidence that both can co-exist.

Evidence has been presented that high school students are using the engineering design process in this course through qualitative research methods. In the qualitative tradition of inquiry, this study analyzed data presented; however, not all participants provided journals, reports or even attended class on a regular basis. These students were not formally interviewed and thus, data presented here is limited. Additionally, students vary in their ability to articulate thoughts in conversation and written documents, thus in reviewing these data, it was noted that future study might involve additional data collection, such as formal stratified student interviews to further triangulate findings.

Engineering design challenges are one potential avenue for facilitating the understanding of engineering through hands-on application. Technology education historically has been the window through which students apply what they have learned in a relevant hands-on fashion. Utilizing the tools specific to engineering in concert with technology education's hands-on approach may facilitate expanding students' technological literacy. Students in technology education typically use many tools such as material processing equipment, computer aided design software and teamwork to solve problems. Engineering adds additional tools to the experience in the classroom. The extent to which engineering design is applied in the classroom is related to the developmentally appropriate nature of student learning just as the decision to use power tools (and which ones) in material processing problems. These engineering tools and processes may be developed into the technology education curricula for research and testing. All current students and future community members are directly or indirectly impacted by decisions of engineers. As high school students begin to understand the critical lens used by engineers to make decisions, they, too, will deepen their understanding of the world shaped by engineers.

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Perceptions of Indiana Parents Related to Project Lead The Way

Gary Werner
McCutcheon High School

Todd R. Kelley
George E. Rogers
Purdue University

Introduction

The nation's public schools serve as the foundation for preparing a workforce that is literate in science, technology, engineering, and mathematics (The National Academies, 2007). In the report, *Rising above the gathering storm: Energizing and employing America for a brighter economic future*, members of The National Academies identified that meaningful and high-wage employment in the new global economy will require technological literacy and engineering skills. Furthermore, the report strongly recommended that ensuring all students develop these technological workplace skills should be the mission of our public schools (The National Academies). Obtaining these essential skills will provide today's students, as well as tomorrow's workers, with "the opportunity to become part of a cadre of world-class scientists and engineers who can create the new products that

Gary Werner is an engineering/technology education teacher at McCutcheon High School in Lafayette, IN. He can be reached at gwerner@tsc.k12.in.us.
Todd R. Kelley is an assistant professor of engineering/technology teacher education at Purdue University in West Lafayette, IN. He can be reached at trkelley@purdue.edu.
George E. Rogers is a professor of engineering/technology teacher education at Purdue University. He can be reached at rogersg@purdue.edu.

will in turn broadly enhance the nation's standard of living" (The National Academies, p. 135). The National Academies went on to note that high-quality secondary engineering instruction is grounded in a high-quality and rigorous K-12 engineering curriculum.

Integrating Project Lead The Way

According to Douglas, Iversen, and Kalyandurg (2004), teaching engineering classes in high school has also been supported by the American Society of Engineering Education. Furthermore, Colvin (2005) indicated that the push for secondary engineering education was fueled by concern of a predicted future shortage of engineers in the United States. The National Academies (2007) stated that Project Lead The Way (PLTW) was the model engineering curriculum to address the nation's technological workforce needs. PLTW was introduced in 12 New York high schools in 1997 (Blais & Adelson, 1998). Since then schools across the country have adopted the PLTW engineering program. In 2008, the PLTW curriculum was offered by schools in all 50 states and the District of Columbia and totaled 3,000 schools (PLTW, 2008). The purposes of PLTW are to develop technologically literate high school graduates, to generate interest in engineering-related fields, and to encourage high school students to pursue engineering as a career pathway. PLTW's target population was students that are already on a college career path, such as honors or academic honors high school diploma. The curriculum that PLTW developed was rigorous, demanding, and designed to help students prepare to study engineering careers in the future (Kelley, 2008). The PLTW program offers seven engineering courses in its high school engineering curriculum.

High schools in Indiana have implemented PLTW curriculum into their schools since 2001. Indiana technology education teachers have accepted PLTW as a beneficial component of technology education, even though the PLTW is a departure from the standard technology education curriculum (Rogers, 2005). In 2006, Indiana schools offering PLTW programs grew to 231 schools; an increase of 45 % from 2005. With this increase, Indiana became the nation's leader in implementing the PLTW curriculum (PLTW, 2006.).

Parental Influence

In order for the PLTW curriculum to expand, recruit, and educate more students it is important for parents to understand what the PLTW engineering curriculum has to offer their sons or daughters. Studies have indicated that parents play the most significant role in adolescents' career decision making (Hoffman, St. Louis, & Hoffman, 2010; Noel-Levitz, 2009; Otto, 2000; Saiti & Mitrosili, 2005). "Parental involvement can certainly play a large role in the college decisions of perspective students" (Noel-Levitz, p. 5).

Both Noel-Levitz (2009) and Teachman and Paasch (1998) have noted that the family income and the educational level of the child's parents can both have an effect on the child's career decision. Additionally, the occupation of the child's mother and father has shown to influence students' career paths (Trice, 1991). Hoffman, St. Louis, and Hoffman (2010) noted that parents who are engineers shape their daughters' perception of an engineering career pathway. Mothers have been shown to have a greater influence on a child's career decisions than fathers (Mickelso & Velasco, 1998).

Saiti and Mitrosili (2005) noted that parents' involvement in guiding their child's career decisions has become a concern with educational policy makers. The departments of education in some states have created programs to help parents partner with their children to determine the most appropriate career choice (Kucker, Smith-Rockhold, Bemis, & Wiese, 1998). Likewise, programs that provide instruction to lead to a career pathway in engineering should also include looking to parents as an important partner to recruit and retain students in these courses. However, it is unclear how knowledgeable parents of PLTW students are regarding the PLTW program.

Problem Statement

Currently there is a lack of data related to parents' perceptions of high school engineering education (PLTW) and its effect on their child's career goals.

Purpose of the Study

The purpose of this study was to determine the current perceptions of PLTW held by parents of students enrolled in PLTW engineering courses at one Indiana high school. This study was guided by the following research questions:

1. What are the current perceptions held by parents about Project Lead the Way?
2. Does a parent's income affect their perception of PLTW?
3. Does a parent's gender affect their perception of PLTW?
4. Does a parent's level of education affect their perception of PLTW?

Methodology

This descriptive research study gathered information from a high school in northeastern Indiana. Best and Kahn (2006) suggested that a quantitative survey was best suited for this type of construct and their procedures were followed to develop the survey instrument. The population and sample of this study considered all parents (N = 147) who had a child enrolled during the second semester of the 2009 school year in one or more of the PLTW classes offered by the school, which included *Principles of Engineering* (54 parents), *Introduction to Engineering Design* (75 parents), and *Civil Engineering and Architecture* (18 parents) courses. The response rate of the parents was 57.1% (N = 80).

The survey instrument collected demographic information and contained questions that had been modified from a similar study (Rogers, 2006). The demographic information consisted of five categories: a) highest level of education completed; b) family's gross income per year; c) ethnicity; d) gender; and d) employment. Parents' perceptions were assessed based on these five statements:

1. PLTW classes benefit my child.
2. After taking a PLTW class, my child has more knowledge of engineering.
3. My child is more interested in an engineering career.
4. My child is more likely to major in engineering in college.
5. PLTW classes have taught my child concepts that have helped him/her in other classes.

The respondents rated each statement using a five-point Likert-type scale, with Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, and Strongly Disagree = 1.

Limitations of the Study

1. Due to various constraints, this study was limited to one Indiana high school.
2. Conclusions drawn from this study may only be applied to one Indiana high school. This study's findings cannot be generalized to the entire national population of PLTW parents.

Results

All responding parents had completed high school. Nearly equal proportions of respondents reported three primary levels of education with 27.8% of parents indicated completing some college education/associate degree, 25.3% noting they had earned a bachelor's degree, and 26.6% had a received a high school diploma/GED. Table 1 outlines the highest level of education completed by the respondents.

Table 1. Highest level of education completed

Level of Education Completed	*n*	%
Associate degree or some college	22	27.8 %
High school graduate/GED	21	26.6 %
Bachelor's degree	20	25.3 %
Post baccalaureate credits	6	7.6%
Master's degree	10	12.7 %
Doctoral degree	0	0 %

Sixty-two parents (81.6%) indicated that their family income was $50,000 or more per year. The largest income level reported was $100,000 or above (35.1%, n = 27). A family income of $49,999 and below accounted for the smallest percentage reported (19.5%, n = 15). Gross family annual income is noted in Table 2.

Table 2. Gross family annual income

Family's Gross Income per Year	*n*	%
$0-$24,999	3	3.9 %
$25,000-$49,999	12	15.6 %
$50,000-$74,999	16	20.8 %
$75,000-$99,999	19	24.7 %
$100,000 or above	27	36.1 %

Parents were asked to indicate their ethnicity. Parents who indicated white-non Hispanic represented the largest group (n = 70, 87.5%). (See Table 3) When asked to indicate their gender, 67.1% (n =53) indicated gender as female. (See Table 4) This indicated that mothers of students completed the majority of the surveys.

Table 3. Ethnicity

Ethnicity	*n*	%
African American; Black	0	0 %
Asian American; Pacific Islander	3	3.8 %
White; Non-Hispanic	70	87.5 %
Hispanic; Latino(a)	4	5 %
Native American; Alaska Native	0	0 %
Other	1	1.3%
Prefer not to respond	2	2.5%

Table 4. Gender

Gender	*n*	%
Male	26	32.9 %
Female	53	67.1 %

Parents were asked to indicate their type of employment. The survey revealed that 20 respondents (25.6%) were employed in a managerial position. Equal percentages of parents were employed in the education (15.4%, n = 12) and professional areas (M.D., Lawyer, DVM, etc.) (15.4%, n = 12). Clerical, skilled trades/crafts, sales/marketing, and service accounted for the remaining (n = 34, 43.6%) respondents. Table 5 notes employment information from survey respondents.

Table 5. Type of Employment

Type of Employment	*n*	%
Clerical	8	10.3 %
Education	12	15.4 %
Managerial	20	25.6 %
Professional	12	15.4 %
Sales/Marketing	9	11.5 %
Service	7	9.0%
Skilled Trades/Crafts	10	12.8%

The college credit section revealed that 60.8% (n = 48) of the parents surveyed were aware that their child could receive college credit for PLTW classes. However, 39.2% (n = 31) of the respondents were not aware that college credit could be earned by taking PLTW classes. Even though 60.8% of parents knew that their child could receive college credit for completing PLTW classes only 21.5% (n = 17) indicated they knew which colleges accepted PLTW college credits. Parents' perceptions of the PLTW college credit are noted in Table 6.

Table 6. College Credit for PLTW classes

College Credit for PLTW classes	*n*	%
Awareness that college credit is available		
Yes	48	60.8 %
No	31	39.2 %
Knowledge which colleges accept PLTW credit		
Yes	17	21.5 %
No	62	78.5 %

A total of 96.1% (n = 75) of the parents indicated they thought PLTW classes would benefit their child. When asked if their child has more knowledge of engineering after taking a PLTW class, parents responded positively with 94.9% (n = 74) by noting they agreed or strongly agreed with this statement. Concerning the statement, my child is more interested in an engineering career, the response was 70.8% (n = 55) strongly agree or agree with the statement. However, 24.4% (n = 19) were neutral on whether their child is more interested in an engineering career after taking a PLTW class. Forty-two parents (54.6%) indicated that they strongly agreed or agreed that their child is more likely to major in engineering in college because of taking a PLTW course. Contrasted by 37.7% (n = 29) who noted a neutral response to this item. Concerning the statement that PLTW classes have taught my child concepts that have helped him/her in other classes, 45.5% (n = 35) of the parents indicated agreement, and 33.8% (n = 26) noted they strongly agree. A complete breakdown of the parents' responses can be seen in Table 7.

Table 7. Level of agreement with the following statements

	Strongly Agree		Agree		Neutral	
	n	%	n	%	n	%
PLTW classes benefit my child.	43	55.1	32	41.0	2	2.6
After taking a PLTW class, my child has more knowledge of engineering.	46	59.0	28	35.9	3	3.8
My child is more interested in an engineering career.	32	41.3	23	29.5	19	24.4
My child is more likely to major in engineering in college.	32	41.6	10	13.0	29	37.7
PLTW classes have taught my child concepts that have helped him/her in other classes.	26	33.8	35	45.5	12	15.6

Table 7 (continued).

	Disagree		Strongly Disagree			
	n	%	n	%	M	SD
PLTW classes benefit my child.	1	1.3	0	0	4.50	0.61
After taking a PLTW class, my child has more knowledge of engineering.	1	1.3	0	0	4.50	0.63
My child is more interested in an engineering career.	3	3.8	1	1.3	4.05	0.96
My child is more likely to major in engineering in college.	4	5.2	2	2.6	3.85	1.10
PLTW classes have taught my child concepts that have helped him/her in other classes.	3	3.9	1	1.3	4.06	0.87

Mean Likert-type scale responses noted that parents indicated that PLTW classes were beneficial to their son or daughter (M = 4.50, SD = 0.61) and that their child was more knowledgeable about engineering as a result of the PLTW course (M = 4.50, SD = 0.63). Overall, parents agreed their children were more interested in engineering following a PLTW course (M = 4.05, SD = 0.96) and that the PLTW course taught their son or daughter concepts that helped in other coursework (M = 4.06, SD = 0.87). Parents were less in agreement that their child was more likely to major in engineering following a PLTW course (M = 3.85, SD = 1.10). However, a mean of 3.85 still noted agreement with this statement.

Responses of the parents based on their reported annual income noted overall strong agreement with PLTW courses benefitting their children (M = 4.3 to M = 4.6) and that the

PLTW course made their child more knowledgeable about engineering (M = 4.3 to M = 4.8). (See Table 8.) Two items noted a slight disparity between income levels. Parents whose annual income was between $25,000 and $75,000 noted their child was more interested in engineering following a PLTW course (M = 4.2 to M = 4.3), while parents with an income of less than $25,000 per year indicated a neutral opinion (M = 3.3, SD = 0.57). This was also indicated related to their child being more likely to major in engineering in college (M = 4.2 & 4.0 to M = 3.3).

Table 8. Means by gross family income

	$0 -$25K		$25K-$49K		$50K-$75K	
	M	SD	M	SD	M	SD
PLTW classes benefit my child.	4.3	0.57	4.5	0.90	4.5	0.74
After taking a PLTW class, my child has more knowledge of engineering.	4.3	0.57	4.8	0.45	4.4	0.82
My child is more interested in an engineering career.	3.3	0.57	4.2	1.10	4.3	0.89
My child is more likely to major in engineering in college	3.3	0.57	4.2	1.20	4.0	1.20
PLTW classes have taught my child concepts that have helped him/her in other classes.	4.0	0.00	4.3	0.77	3.7	1.10

Table 8 (continued)

	$75,000-$100K		$100K-Above	
	M	SD	M	SD
PLTW classes benefit my child.	4.6	0.49	4.4	0.50
After taking a PLTW class, my child has more knowledge of engineering.	4.6	0.68	4.5	0.57
My child is more interested in an engineering career.	3.9	1.10	4.1	0.83
My child is more likely to major in engineering in college	3.8	1.08	3.8	1.06
PLTW classes have taught my child concepts that have helped him/her in other classes.	4.2	0.89	4.1	0.76

Male parents noted very strong agreement with PLTW classes being beneficial to their child (M = 5.0, SD = 0.58), while mothers did not indicate as strong an agreement (M = 4.5, SD 0.63). Other responses compared by gender indicted very little difference based on gender of the parent. Responses based on the gender of the parent are noted in Table 9.

Table 9. Means by Gender

	Male		Female	
	M	SD	M	SD
PLTW classes benefit my child.	5.0	0.58	4.5	0.63
After taking a PLTW class, my child has more knowledge of engineering.	4.5	0.58	4.5	0.81
My child is more interested in an engineering career.	4.2	0.77	4.0	1.03
My child is more likely to major in engineering in college.	4.0	0.99	3.8	1.15
PLTW classes have taught my child concepts that have helped him/her in other classes.	4.3	0.73	4.0	0.93

Discussion

As mentioned above, some studies have indicated that parents play the most significant role in adolescents' career decision making (Hoffman, St. Louis, & Hoffman, 2010; Noel-Levitz, 2009; Otto, 2000; Saiti & Mitrosili, 2005) and it is critical to locate methods to help parents to work with their children to select appropriate career choice (Kucker, Smith-Rockhold, Bemis, & Wiese, 1998). Considering the important role parents play in helping their children prepare for their future, the results of this study provides vital information for PLTW leadership, PLTW teachers, and PLTW students and parents. The study found that parents' perceptions of PLTW had the greatest variation in the understanding of college credit that can be earned for successfully completing PLTW classes. The PLTW parents surveyed possessed a limited knowledge when surveyed about college credit applied to PLTW courses. A total of 39.2% (n = 31) of parents were not aware that PLTW classes could earn college credit. Additionally, 78.5% (n = 62) stated that they did not know what colleges and universities accepted the PLTW classes for credit. This is a critical finding when considering the influence parents have on their child's high school course selection and on their career choice (Quast, 2003).

Furthermore, many secondary education programs like PLTW are being cut or eliminated due to recent reduced state funding. The research findings presented here suggest that the parents of PLTW students are uninformed of the benefits of PLTW courses regarding college credits. PLTW leadership and PLTW teachers should develop better strategies to inform parents about the college credits available through PLTW.

Another interesting finding of this study was that demographics of the family's gross annual income affected parents' perceptions of PLTW. The study found that parents from families with incomes greater than $25,000 believed that PLTW courses developed more interest in engineering for their child and that their child was more likely to enter engineering as a college major. However, families with an annual income of less than $25,000 did not agree or were neutral that PLTW course generated interest in engineering or that their child was more likely to enter engineering as a college major. This finding may indicate that lower income parents do not see a college engineering pathway as an option for their sons and daughters. One possible reason for these results could be due to parents responding to this item based upon their limited ability to provide college tuition for their child. It is ironic that the population of PLTW students that could benefit the greatest from free college credit for PLTW courses are those of parents who perceive PLTW with limited or no benefit for their child regarding opportunities to pursue engineering at the college level. Armed with the results of this study, school officials, PLTW teachers, and PLTW leadership should develop strategies to address the need to inform parents about the benefits of PLTW college credit options. Although the results of this study cannot be generalized to all PLTW programs around the nation, these results indicate that this is a feature of PLTW that should be communicated more clearly.

The research noted that mothers do not believe that PLTW classes are as beneficial for their child to the same degree as fathers. It is not clear whether both mothers and fathers completed the survey together and only the female demographic classification was marked or whether this is a valid disparity. However, in Rogers' (2007) study, female principals sampled indicated the highest Likert-type rating for the positive effect of PLTW on students' motivation, problem solving skills, enthusiasm, and critical thinking skills. Both studies indicated that female principals and both mothers and fathers felt PLTW classes were beneficial to their students and children.

Implications

This study generated two specific implications. These results should be shared with high school technology education teachers and counselors and pursued in future studies.

1. The finding that parents with a higher gross income had a strong perception of PLTW should lead teachers, counselors, and administrators to ensure that students from low socioeconomic families are provided career guidance for the engineering pathway.
2. The finding that fathers have higher rated perceptions of PLTW than mothers should be investigated further especially considering the finding of Mickelso and Velasco (1998) who noted that mothers have a greater influence on their child's career decisions than fathers.

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