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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.

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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.

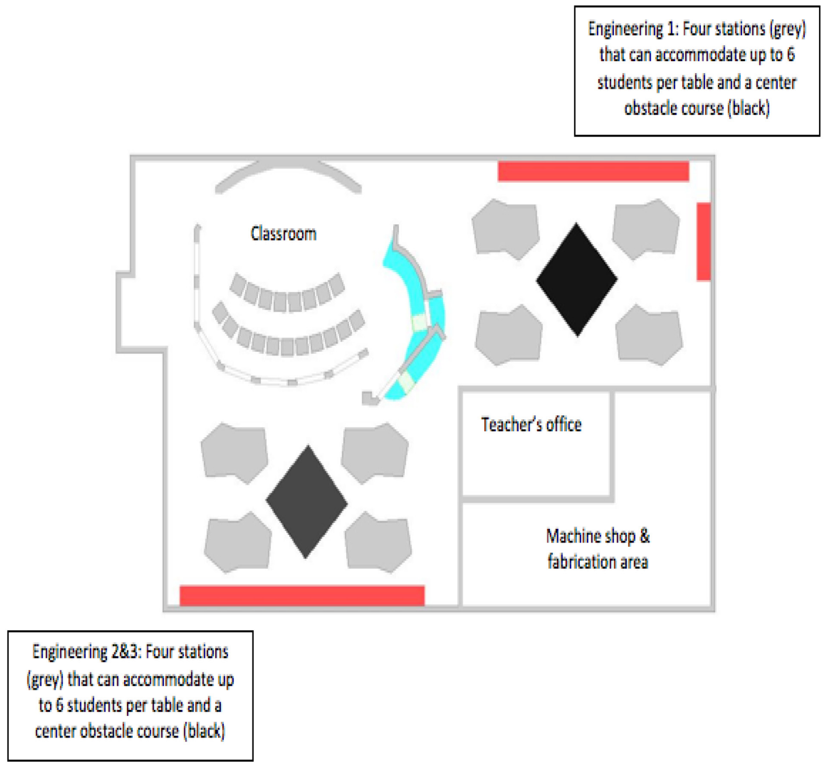
Kersting (2003) acknowledged that there are possible similarities and differences in creativity as it relates to people in the sciences and arts: "Science has to be constrained to scientific process, but there is a lot less constraint on artists. Many artists come from more chaotic environments, which 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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