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Transfer of Learning: Connecting Concepts During Problem Solving

A concern of many educators and managers is students' ability to transfer concepts and procedures learned in school to the work environment. According to the Committee on Science (2007) the high school experience does not provide enough authentic problem-solving and project-based activities for students to be prepared mentally for the types of problems they will have to solve in the real world, or at their place of employment. When children are taught a skill, such as solving a mathematical problem, they often fail to recognize that their new skill can be used to solve a similar problem outside of school (Bereiter, 1984). In other cases, students who are skilled with certain tasks outside of school often have difficulty transferring concepts learned from these experiences (Lave, 1988; Johnson, 1997; Johnson, Dixon, Daugherty, & Lowanto, 2011) to the solving of well-structured problems in schools, such as those often found on mathematics and science tests. These findings demonstrate the inability of students to recognize the transferability of concepts learned from solving well-structured problems in the classroom to ill-structured problems faced outside of the classroom and also the transferability of concepts learned from solving ill-structured problems, similar to those encountered in the real world, to the solving of well-structured problems encountered in the classroom.

Brophy, Klein, Portmore, and Rogers (2008) are of the opinion that we have to urgently change the way in which we teach students in order to address their inability to effectively transfer concepts. The changing nature of work accentuates the need for this radical shift. In order to mitigate the need for extensive retraining at great cost to organizations it is critical that workers are able to transfer their knowledge to new situations quickly and efficiently (Johnson, 1995). Various curricula and outreach programs, such as Design, Technology, and Engineering for All Children, Engineering by Design™, Project Lead the Way, Engineering is Elementary®, LEGO® Engineering, and others, offer various types of problem-based and project-based experiences, which engage students in authentic problem solving (Jeffers, Safferman, & Safferman, 2004). These learning initiatives help to improve students' ability to transfer knowledge, concepts, and skills learned in schools to real-life contexts. Some of these curricula, such as Engineering by Design™ and Project Lead the Way, use

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engineering principles and design as a framework for learning STEM concepts and processes (Nathan, Tran, Phelps, & Prevost, 2008). The ontology of engineering education provides a framework that supports the acquisition of a wide range of knowledge and skills that are associated with STEM.

The low performance of students on standardized tests, however, is still a major concern for educators and the general public. While these curricula offer more authentic problem solving, it is not clear if these experiences also allow students to connect learned concepts to the solving of mathematics and science standardized test items. This study focuses on one such curriculum—Project Lead the Way (PLTW)—a multi-year, problem-based/project-based pre-engineering curriculum that is used by some schools in their engineering and technology education program (Tran & Nathan, 2010). Since a large portion of the PLTW objectives emphasize content from mathematics and/or science standards (Project Lead the Way [PLTW], 2008), it is the authors view that students should be able to demonstrate the ability to connect concepts learned from engaging in PLTW curriculum activities to the solving of mathematics and science test problems in the classroom.

Purpose of the Study

The purpose of this study is to determine if PLTW students are able to better transfer mathematics, science, and design concepts from one situation to another than students who have not taken the PLTW courses and the extent to which students are able to make connections to concepts learned in the PLTW courses to concepts that they are required to use when solving standardized test problems. This study is based around the following research questions:

- Is there a relationship between the mathematics, science, and design performance of students and the number of PLTW courses they have taken? Is there a difference in the mathematics, science, and design performance of students who have taken PLTW courses and those who have not taken a PLTW courses?
- To what extent are students able to associate concepts learned in the PLTW curriculum with concepts required to solve mathematics, science, and design problems?

Transfer of Learning

There are several factors that affect learning transfer. These include whether students understand or simply memorize knowledge, the amount of time spent on learning the task, the amount of deliberate practice that is done beyond learning the task, the motivation of the student, how the problem is represented, the transfer conditions, and the metacognition of the solver (Dweck, 1989; Ericsson, Krampe, & Tesch-Romer, 1993; Johnson et al., 2011; Palinscar & Brown, 1984; Singley & Anderson, 1989).

Two broad categories of transfer are described in the literature—near transfer and far transfer. According to Johnson (1995) near transfer occurs when students apply their knowledge and skills in situations and contexts that are very similar to those in which the learning occurred. In contrast, a far transfer occurs when a skill is performed in a context that is very different from the context in which the skill was learned. The opportunities for far transfer in problem solving within schools are understandably not as regular as the opportunities for near transfer. Far transfer is more difficult "because students must deliberately analyze the situation in order to recall the rules or concepts that are needed to apply their knowledge and skill in that particular situation (Salomon, 1988)" (p. 34).

Good and poor problem solvers differ in their recall of information from previously encountered problems and by extension their ability to transfer concepts to the target problem. This difference exists because poor problem solvers tend to remember surface similarities between problems, while good problem solvers remember underlying conceptual structures that make two problems similar although they have different surface features (Sutton, 2003). This ability of good problem solvers makes it easier to transfer concepts learned in other domains or from solving other types of problems because of their conscious effort to abstract knowledge and concepts from one context for application to another (Johnson, 1995). Cognitive research shows that the organization of learning and how new learning relates to what a student already knows are the strongest predictors of how well a student will transfer knowledge (National Research Council, 2000). Schunn and Silk (2011) articulated, however, that in science and engineering students often "lack relevant conceptual frameworks or have frameworks that are not developed enough to support new learning adequately" (p. 9). The absence of such frameworks makes it difficult for students to connect and apply other knowledge where relevant.

Key Components in the Learning Transfer Process

Sutton (2003), stated that "the problem-solving process involves several aspects from which three major facets tend to emerge: the solver's representation of the problem, the solver's background experiences, and the solver's understanding of the problem" (p. 56). The problem solving process begins as soon as the problem solver generates enough information about the problem space to gain an understanding of the problem. Often, the problem solver is able to associate concepts from previous experience to solving a similar problem. This association with analogous concepts may originate from some form of prompting about the similarity, or the two problems may share similar surface features that the problem solver recognizes (Gick & Holyoak, 1980; Needham & Begg, 1991). Sometimes the problem provides retrieval cues that permit access to relevant clues that in turn aid in the transfer of concepts and knowledge. According to Perfetto, Bransford, and Franks (1983), most problem-solving situations involve cases in which problem solvers are uninformed. They are not provided with any clues or prompt about previously learned concepts that can aid in the solution, and so they engage in self-generation of potential answers to the problem solution. That being the case, it would seem relevant that studies also address the question of how information can be transferred under a "condition in which students are not explicitly informed about a particular acquisition context that is relevant to problems they confront" (p. 31).

Representation. Representation in the problem-solving process refers to how the solver mentally represents the problem. The solver's representation of the problem is directly related to his or her existing knowledge structure of the content of the problem. The advantages of abstract problem representations have been studied in the context of algebra word problems. "Students who were trained on specific task components without being provided with the principles underlying the problems, could do specific tasks well but they could not apply their learning to new problems. By contrast, the students who received abstract training showed transfer to new problems that involved *analogous* relations" (National Research Council, 2000, p. 63). Research also shows that engaging students in the solutions of different types of problems in different contexts can enhance transfer by enabling learners to think flexibly about complex domains (Spiro, Feltovitch, Jackson, & Coulton, 1991). Various types of mental representations are used by students and experts alike in order to understand a problem and to facilitate transfer, particularly, but not limited to, representations such as analogies, metaphors, and propositions are used in the solving of ill-structured problems such as engineering design (Hey, Linsey, Agogino, & Wood, 2008; Lewis, 2008; Paivio, 1990).

Understanding. A student's comprehension of a problem and his or her ultimate ability to transfer concepts learned previously to the current problem is inextricably linked to his or her ability to properly represent the problem. Embedded within each representation are concepts that the solver deems analogous to the problem being tackled, and he or she will transfer these concepts to arrive at a satisfying solution. A philosophical underpinning of programs that integrate the STEM domains is the learning of concepts in one domain, such as science or technology, will facilitate the learning of concepts in other domains, such as mathematics or engineering. Students who can identify the connection between concepts across domains will likely demonstrate an understanding of the problem. While a superior understanding of a problem is demonstrated by the transfer of concepts, knowledge, or processes without prompting, sometimes the use of prompting is necessary. According to Gick and Holyoak (1980; 1983) and Perfetto et al. (1983), prompting can dramatically improve the rate of transfer in problem solving.

A good understanding of the problem will also be reflected in how solvers use metacognitive skills. Metacognition refers to how problem solvers are able to self-regulate the strategies that they use. When students are cognizant of the requirements of a problem, they will more proficiently focus on critical elements of the problem, connect or abstract common themes from previous problem solving episodes or learning experience, and evaluate their progress towards the right solution for well-structured problems or a good solution for ill-structured problems (Sutton, 2003; National Research Council, 2000).

Experiences. Each student's experience differs. Different individuals have different conceptual knowledge and will make different associations to their knowledge. Exposure to the constraints and affordances of a particular context in which a problem exists will invariably influence the way in which the student represents a problem in a similar context. According to Sutton (2003), the solver's prior experience helps to establish an understanding of the problem. The process of understanding is iterative, and full understanding is often complex. When the problem solver completely understands the problem and its underlying structure, then transfer to similar situations can occur.

Students bring a wealth of knowledge to each learning situation and, without specific guidance from teachers, may fail to connect everyday knowledge to subjects taught in schools (National Research Council, 2000). As students' metacognitive skills develop, their ability to make connections to their learning experiences in school and beyond the walls of the classroom becomes more self-regulated and automatic when solving problems. The nature of activities within problem-based and project-based curricula can aid in authenticating the problem-solving engagements by students so that both near and far transfer becomes more fluid. Transfer between tasks is a function of the similarity of transfer tasks and learning experiences. Transfer is therefore affected by the context of the original learning; so, people can learn in one context and yet fail to transfer in other contexts. When students are exposed to multiple contexts in their instructions that include examples that demonstrate a wide application of what is being taught, they develop a flexible representation of knowledge and are likely to abstract the relevant features of concepts that make two unique problem scenarios similar (Gick & Holyoak, 1983; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987).

One view of learning transfer is that students find it difficult to transfer concepts that they learn in schools to the real world because education simplifies material to make it easier to teach (Spiro et al., 1991). However, problem-based learning may not suffer from a lack of context or an oversimplification of content. There is a growing sentiment that learning of this form, which utilizes problem-based and project-based activities, can enhance students' general learning transfer and problem-solving skills (Hmelo-Silver, 2004). For example, Lachapelle and Cunningham (2007) found that Engineering is Elementary, one of the largest elementary engineering curricula that focuses on integrating engineering with reading literacy and existing science topics in the elementary grades, can improve students' knowledge and comprehension of general engineering, technology, and science concepts. Mahalik, Doppelt, and Schunn

(2008), in an examination of the effectiveness of design-based instruction, found that the design-based approach for teaching middle school science is associated with improvement in science achievement, engagement, and retention of science concepts.

Project Lead the Way

PLTW is a non-profit organization that works with public schools, the private sector, and higher education to increase the quantity and quality of engineers and engineering technologists by providing high school students with engaging pre-engineering activities. They provide curricula for both middle and high schools. The standard-based pre-engineering curriculum, Pathway to Engineering, is designed for high schools. It challenges students to solve real-world engineering problems by applying their knowledge and skills in mathematics, science, and technology. The four year engineering sequence consists of eight hands-on courses; two are foundation courses (Introduction to Engineering Design and Principles of Engineering) five are specialized courses (Aerospace Engineering, Biotechnical Engineering, Civil Engineering and Architecture, Computer Integrated Manufacturing, and Digital Electronics) and one is a capstone course (Engineering Design and Development) (PLTW, 2012).

A recent study by Tran and Nathan (2010) investigated the relationship between pre-college engineering studies and student achievement in mathematics. Their findings (using multilevel statistical modeling with 140 students nested within teachers) showed that while students gained in mathematics and science achievements up to tenth grade, students enrolled in PLTW foundation courses showed significantly smaller math assessment gains than those in a matched group that did not enroll, and there was no measurable advantage on science assessments when controlling for prior achievement and teacher experience.

Another study conducted by PLTW (2008) described the alignment of learning activities in PLTW curriculum, Introduction to Engineering Design (IED), with mathematics and science standards. The study showed that, generally, a large proportion of the objectives in the IED course emphasizes content from the mathematics and/or science standards, a large proportion of the objectives dually emphasize mathematics and science content, and objectives across the curriculum that emphasize mathematics and science expect students to employ concepts and skills and use short-term strategic thinking. According to PLTW, the need to show the relevance of the interconnection of STEM to what students are learning is more important than ever in order to excite more students about STEM careers.

Method

An embedded design mixed method framework (Creswell, 2008) was used as the method of this study. Mixed method studies that utilize the embedded design gather both qualitative and quantitative data, but “one form of data plays a supportive role to the other form of data” (Creswell, 2008, p. 558). In this study the quantitative data was given priority as the main source of data, and the qualitative data played a supportive role. This study utilized a non-experimental design, as it used intact classrooms and no attempt was made to manipulate the variables or treatment.

Participants

A convenience sample was selected. The participants were students at a Midwestern high school. The school of nearly 1,500 students is located in a rapidly growing metropolitan area on the fringe of a large city. According to the public data regarding the school, the student population is nearly 90 percent white, only two percent of the students in the district live below the poverty line, and upon graduation 90 percent of the students attend a post-secondary institution. The Engineering/Technology Education department has three full time teachers and offers a wide range of traditional technology education courses as well as six PLTW courses (Introduction to Engineering Design, Principles of Engineering, Aerospace Engineering, Civil Engineering and Architecture, Computer Integrated Manufacturing, and Engineering Design and Development). Participation in this study was offered to two upper level PLTW classes (Civil Engineering and Architecture and Engineering Design and Development) and two advanced mathematics and science classes (AP Physics and AP Calculus).

Thirty-eight students from PLTW courses and 25 mathematics and science students obtained parental consent, provided personal assent, and participated in the study. Group 1 ($N = 25$), referred to as non-PLTW students, consisted of students who had not taken any PLTW courses. Of this amount, 5 were juniors and the remaining 20 were seniors. All juniors had previously completed mathematics courses such as Algebra I, Algebra II, Geometry, and Trigonometry, and one student had completed a statistics course. Science courses completed by juniors included biology, chemistry, and physics. One of the juniors completed an additional AP Physics course, and another completed an additional AP Biology course. The seniors had taken additional mathematics courses such as Pre-Calculus, Calculus, and Probability and Statistics. Additional science courses taken by seniors include AP Chemistry, Zoology, Microbiology, Anatomy, AP Environmental Science, Biotechnology, and Astronomy.

Group 2 ($N = 38$), referred to as PLTW students, consisted of students who had completed the mathematics and science courses required of PLTW (or some of the courses, in the case of juniors and sophomores) and also had taken one or more PLTW courses. Three students were sophomores, 17 were juniors, and 18 were seniors. Five students had taken two PLTW courses, 18 had taken three PLTW courses, 14 had taken four PLTW courses, and one student had taken five PLTW courses.

The groups' sample sizes were well within the range that is required for Pearson's correlation to detect significant correlation between two variables and for an independent *t*-test to detect a significant difference in students' scores with a statistical power of .80. According to Cohen (1988), a Pearson's correlation test requires a minimum sample size of twenty-one for a large effect size and a one tailed alpha of .05. Also, for an independent *t*-test, a minimum sample size of twenty-one cases per group is needed for a large effect size and a one tailed alpha of .05.

Data Collection and Analysis

All students that consented to participate in the study were asked to complete a test instrument that was divided in three sections—mathematics, science, and design. The mathematics and science sections each consisted of five test items taken from past standardized tests. The items were then vetted by four teachers, two from mathematics and two from the sciences, to ensure consistency in the difficulty level of the test items. Answer sheets were prepared for each test item by a mathematics and science teacher. The design problem represented an ill-structured engineering problem that required students to use their knowledge of math, science, and technology to solve. The problem was adopted from an engineering design textbook. Several possible solutions were provided by the design textbook. In addition to answering the questions, the PLTW students were asked to write down the PLTW concepts or activity that best equipped them to answer each particular question. The non-PLTW students were not asked this question. Completed tests were scored by two teachers using the answer sheets that were provided.

Numerical scores were then assigned to each test section and calculated to determine an overall score. SPSS analysis of the scores found the distributions to be normal and of similar variance. A Pearson's correlation test was then run to determine if a relationship existed between the number of PLTW courses that a student had taken and their performance on the overall test and the design, mathematics, and science components of the test. Then an independent t-test was performed to determine if a significant difference existed between the means of the PLTW students and the non-PLTW students on the overall test and each subsection. Lastly, the qualitative data was analyzed to determine if students were able to connect the concepts that were presented in the instrument with the courses in which they were presented with those concepts.

Findings

We found significant relationships between the number of PLTW courses students took and students' performance in design score and total score. Also, there was no significant difference in mathematics and science performance between PLTW and non-PLTW students. PLTW students, however, performed significantly better on the design component of the test.

Pearson's correlation analysis shows a significant positive correlation between the number of PLTW courses taken and the students' score on the design component of the test ($r = .33$, $\rho < 0.05$). There was a significant positive correlation between the number of PLTW courses taken and students' combined or total score on the test ($r = .36$, $\rho < 0.05$). In other words, the scores of the students who have taken more PLTW courses increased significantly on the design component of the test and on the total score on the test. Although these variables have statistically significant relationships, this relationship is considered weak because the number of PLTW courses only explains 11% and 13% variances of the design scores and the total scores respectively. In other words 89% and 87% of the variances in the design scores and total scores respectively can be attributed to other factors.

Table 1
Correlation Matrix (N = 38)

	# of PLTW	Total Score	Design Score	Math Score	Science Score
# of PLTW	1.00				
Total Score	.35*	1.00			
Design Score	.33*	.59**	1.00		
Math Score	.19	.68**	.15	1.00	
Science Score	.18	.72**	.17	.17	1.00

**Correlation is significant at the 0.01 level (1-tailed)
*Correlation is significant at the 0.05 level (1-tailed)

There was also a significant positive correlation between students' total scores and their performance on the mathematics ($r = .68$, $\rho < 0.01$), science ($r = .72$, $\rho < 0.01$), and design ($r = .59$, $\rho < 0.01$) components of the test (see Table 1).

The results of the independent *t*-test shows a significant difference ($t_{(df = 61)} = 1.933$; $\rho < 0.05$) between the students who have taken one or more PLTW courses and those students who have not taken any PLTW courses on the design component of the test. The PLTW students reported statistically significant higher scores on the design component of the test ($\bar{x} = 37.82$) than those who have not done the PLTW course ($\bar{x} = 26.72$); a mean difference of 11.10. There was no significant difference in the students who have taken PLTW courses and those who have not on the mathematics component ($t_{(df = 61)} = -1.43$; $\rho > 0.05$), science component ($t_{(df = 61)} = 0.009$; $\rho > 0.05$), and overall score on the test ($t_{(df = 61)} = 0.019$; $\rho > 0.05$).

Table 2
Results of Independent T-Test—DESIGN SCORE of Non-PLTW and PLTW

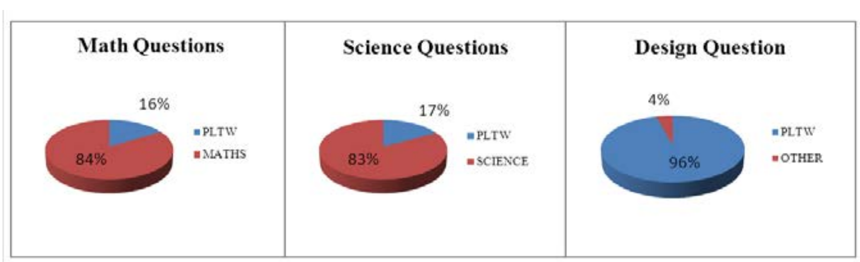
Variable	N	$\bar{x}$	SD	t	ρ *
DESIGN SCORE					
Non-PLTW	25	26.72	21.49	1.93	0.029
PLTW	38	37.82	22.79		

*One-tailed ρ value

Connecting Concepts

A qualitative assessment was done of all the PLTW students with scores at and above the 50th percentile (P_{50}, N = 22) to determine the extent they were able to connect concepts that were learned from the PLTW curriculum to concepts they used to solve mathematics, science, and design items on the test. Not all students were able to explicitly identify concepts that related to the question that they were solving; however, sometimes they could remember the PLTW, mathematics, or science course in which they were introduced to the concept.

Figure 1
Percentage of concepts that were connected with test items



In general, the students with higher scores were able to make more connections to concepts learned from the PLTW curriculum. Figure 1 illustrates that 16% of the concepts identified in the mathematics section, 17% in the science section, and 96% in the design section of the test were connected with concepts that the students attributed to PLTW courses.

Table 3
Connections to Concepts and Courses Made by Students

Test Component	Connected Concepts	Connected Courses
Science Items	Electricity, Circuits, Heat transfer, Beam deflection, Beam calculation, Kinematics, Truss evaluation, V = IR, Velocity,	IDK, POE, CEA, Chemistry, Physics, Integrated Chemistry, Civil Engineering, AP Physics, Aerospace.
Mathematics Items	Percentage, Proportion, SOH CAH TOH, Area width & Length, Pythagoras theorem, trigonometry, Plug and play, Percentage change, Percentage error, Algebra, geometry, Law of sine and cosine, Volume	IE, POE, IDK, Middle School Math, AP Physics, Statistics, Physics
Design Item	Trigonometry, Problem solving, Calculus, Electricity, General math and logic, Material efficiency, Share cost projection, Design process, Geometry,	POE, IED, CEA, EDD, Physics,

Table 3 lists the concepts and courses that students were able to make connection to when solving the mathematics, science, and design test items. Note that abbreviated concepts typically refer to courses taken in the PLTW curriculum (e.g., POE-Principle of engineering; EDD-Engineering design and development; IED-Introduction to engineering design; CEA- Civil engineering and architecture).

Discussion and Conclusions

Because a convenience sample was used, generalized statements about students who take and those who do not take the PLTW courses cannot be made. The findings, however, offer some insight that can be beneficial to engineering and technology educators when teaching STEM concepts. In addition, the authors believe that higher scores were possible if students were given time to prepare for the test, as is usually the norm in schools. The intent, however, was to examine students' ability to make connections under impromptu test conditions.

A small percentage of the students in this study who performed above the 50th percentile were able to connect mathematics and science concepts (16% and 17% respectively) learned in the PLTW curriculum to the problems they were solving. The fact that students were able to identify these concepts means that they believed that these concepts were present in the PLTW courses that they had taken. Their recognition of the concepts may have allowed for greater comprehension of the problem, which likely led to more accurate solutions.

While the PLTW students' performance was significantly better on the design question, the relationship between the number of PLTW courses taken and the scores on the design problems was weak. A possible explanation resides in the nature of the design problem, which required that students also draw heavily on their understanding of mathematics and science concepts. Therefore, topics covered in mathematics and science classes, likely, played a major part in the students' ability to solve the design problem.

There was no significant difference in the overall performance of students in both groups on the mathematics and science items. This indicates that both groups ability to make connection to concepts from previous learning experiences when solving standardized mathematics and science test items are similar. Therefore, it can be assumed that both groups functioned at similar levels of understanding. The PLTW students, however, functioned at a superior level on the design question and the connections they made with mathematics and science concepts. Their ability to make more connections may also be indicative of superior metacognition or self-regulation. However, a research design that uses think-aloud protocols would better provide that type of evidence. Because of their higher scores on this component of the test, the PLTW students accrued higher scores on the total test.

The findings from this study are in some ways consistent with Hartzler's (2000) findings. She conducted a meta-analysis across 30 individual studies of the effects of integrated instruction on students' achievement. She concluded that students in integrated curricula programs outperform students in traditional class on standardized test and state testing programs. In this study, there was no difference in the performance of non-PLTW students and PLTW students on the standardized mathematics and science items. However, the PLTW students' overall performance on the design question was higher.

Since Hartzler's (2000) findings, more intentional efforts are being made to integrate more mathematics and science in project-based and problem-based curricula. The national demand for a STEM workforce makes integrated curricula an essential feature in education. The pedagogy of integrated STEM, however, is still in a nascent stage and more research is needed to clearly define the best strategy to optimize learning by students.

Teaching and reinforcing critical STEM concepts can be very challenging for many engineering and technology educators. While engineering and technology educators want their students to learn STEM, according to Crismond (2011, 2006), their focus is also for students to gain competency in engineering design. Therefore, they would emphasize engineering design concepts such as optimization, tradeoff, troubleshooting, and meeting criteria within prescribed constraints. In order to increase the likelihood of students connecting and transferring STEM concepts in problem solving, engineering and technology educators will need to teach with the intent to improve students' understanding of STEM concepts—rather than teaching primarily for the understanding of engineering concepts. Technology teachers, however, "often lack the pedagogical content knowledge that would make reviewing or re-teaching topics from STEM disciplines efficient and effective" (Crismond, 2011, p. 299).

Sanders (2009) admitted that it is difficult to prepare a teacher that is competent in all three bodies of knowledge, given the volume of content knowledge necessary to be an effective science, mathematics or technology educator. Assuming Sanders' views represent a more realistic assessment of the challenge to prepare STEM teachers, engineering and technology educators will need to work collaboratively with mathematics and science teachers to identify and teach critical STEM concepts that the engineering and technology teacher may lack the competency to teach. This will reinforce previously learned concepts and increase the likelihood of students learning and transferring difficult, abstract mathematics and science concepts and procedures. This pedagogical approach is not without its challenges, as students may still compartmentalize their knowledge. Also, it is often difficult logistically and in terms of instructional timing for teachers across STEM discipline to collaborate effectively (Crismond, 2011; Kimbell & Stables, 2008).

Admittedly, some educators may reason that students should be able see the mathematics and the science in the engineering and technology that they teach. But students may not readily recognize these relationships unless meaningful activities are given to explicitly highlight these connections. As one young machinist admitted at the recent NSF ATE conference in Washington, DC, he did not see the relevance of trigonometry until a senior machinist showed him how to use it to solve a particular machining problem. Similarly, students may not metacognitively see the underlying links between STEM concepts and are unable to transfer the knowledge when it is needed.

Students have to increase their reflective practice to aid their metacognition and transfer of STEM concepts. Math and science concepts that are learnt during engagement with ill-defined problems can easily be forgotten because students' short term memory is "swamped with novel design decisions that must be made and variables that must be considered" (Crismond, 2011, p. 240). The engineering and technology teacher can give students activities that require them to reflect on pertinent STEM concepts—increasing their likelihood of remembering—either in groups or individually and then present their understanding to the class. Students can consult with their mathematics and science teachers, the World Wide Web, libraries, and other learning resources that can aid them in the reflective process. As Johnson (1997) purported, reflective introspection is necessary for quality learning and transfer, even if instruction occurs in rich contexts and involves interaction with peers.

Finally, this study represents a small scholarly endeavor, among many others, to examine whether problem-based and project-based curriculums such as PLTW can also help to improve students' performance on math and science tests. However, in order to make more generalized statement about the effectiveness of these curricula, more robust experimental designs with larger random samples are necessary. In addition, other curricula need to be studied to determine their strengths and weaknesses in making explicit connections to critical math and science concepts. Until student assessment methods are modified to reflect less dependency on standardized tests, engineering and technology educators will garner greater collaboration from math and science teachers when the latter can see that engineering and design-based curriculums does improve students' ability to solve standardized test problems.

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Gender Differences in Interest, Perceived Personal Capacity, and Participation in STEM-Related Activities

Today, more women than in the past obtain degrees in science and engineering (Dean & Fleckenstein, 2007; Hill, Corbett, & St. Rose, 2010). However, women still remain underrepresented in science, technology, engineering, and mathematics (STEM) (Hill et al., 2010). Why, after so many systemic efforts (Liston, Peterson, & Ragan, 2008; Lufkin & Reha, 2009), do women continue to be underrepresented in STEM? Valian (2007) suggested that fewer females than males pursue professional careers in science due to low interest. Valian hypothesized that since individuals make their own choices, some individuals, regardless of the encouragement or support they receive, remain uninfluenced and do not explore STEM-related career options. Are females just not interested in STEM? Jolly, Campbell, and Perlman (2004) proposed that certain components must be in place to increase the likelihood of females pursuing interests in STEM.

Jolly, Campbell, and Perlman (2004) reviewed research and evaluation efforts, as well as reform efforts, in quantitative disciplines that focused on student success in STEM. Several patterns emerged from the research review, which Jolly et al. categorized into three broad-based themes that created the Engagement, Capacity, and Continuity (ECC) Trilogy. Jolly et al. (2004) noted,

> The underlying assumption of the Engagement, Capacity and Continuity Trilogy (ECC Trilogy) is that these three factors must be present for student success. Each of these factors is necessary but individually is not sufficient to ensure student continuation in the sciences and quantitative disciplines. The factors are interdependent. The absence of one can have an impact on the degree to which the others are present. (pp. 3-4)

This paper gives an overview of student engagement, perceived personal capacity, and continuity, as well as describes the gender-related findings of a study that modified and operationalized Jolly et al.'s (2004) ECC Trilogy. The paper also discusses how the findings of this study can be utilized by STEM teachers to understand possible reasons for low female enrollment in their STEM classes.

The likelihood of student engagement in learning a specific topic increases when they possess an awareness, positive attitude, and interest in the topic (Jolly et al., 2004). Jolly et al (2004) suggested that different types of student engagement occur when learning academic disciples. If students feel their social worth will improve as a result of participating in an academic, social, or

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extracurricular activity, they experience behavior engagement (Fredericks, Blumenfeld, & Paris, 2004; Jolly et al., 2004). On the other hand, when students respond positively to the discipline because they find the content itself interesting and intellectually satisfying, they experience emotional engagement (Fredericks et al., 2004; Jolly et al., 2004). Whereas, student interest in mastering concepts that lead to learning more advanced concepts results in cognitive engagement (Fredericks et al., 2004; Jolly et al., 2004). Lastly, students' interest in an activity they find both rewarding and connected to their career goals results in vocational engagement (Fredricks et al., 2004; Jolly et al., 2004). All, or a combination, of these different types of engagement create stronger student interest in the study of an academic area (Jolly et al., 2004).

Students must take prerequisite courses in order to gain an understanding of the advanced content, which in turn increases their capacity for the essential knowledge or skills in an academic area (Jolly et al., 2004). Student motivation increases if they perceive that they can successfully complete a task (Zeldin, Britner, & Pajares, 2008). Therefore, one's level of self-efficacy often acts as a motivator, or not, in pursuing interests in STEM when the task may be difficult (Liu, Hsieh, Cho, & Schallert, 2006; Roue, 2007). If students perceive that they do not possess the necessary math and science knowledge to be successful in a technology and engineering course, they are less likely to enroll in the course (Jolly et al., 2004).

The resources, informal activities, and encouragement or support offered by individuals within a school district create pathways or continuity for students to remain in the STEM pipeline (Jolly et al., 2004). Some researchers have argued that undesirable attitudes and low self-efficacy toward science, technology, engineering, and math negatively influence students' decisions to pursue careers in professional occupations in STEM (Lent, Brown, & Larkin, 1986). However, student involvement in extracurricular activities can be positively linked to their career choices, as well as to their future career goals and plans (Afterschool Allliance, 2009; Chachra, Chen, Kilgore, & Sheppard, 2009).

Methodology

This study employed a descriptive design. The survey responses from students provided measureable evidence to support the use of the ECC Trilogy to identify potential factors related to student interest (or lack of) in becoming an engineer. The research questions were:

1. How do males and females compare with respect to their interest in engagement preferences in technology- and engineering-related activities?
2. How do males and females compare in their perceived personal capacity for doing technology- and engineering-related activities?
3. How do males and females compare in utilizing resources and participating in activities that support STEM-related careers?

4. How do males and females who want to become an engineer compare in their responses within the ECC Trilogy?

Participants

The population for this study included middle school and high school students enrolled in technology and engineering courses in the state of Wisconsin. In order to measure students' interest in becoming an engineer, only students who were enrolled in a contemporary technology and engineering program were invited to complete the survey. The sample included 303 middle school students (grades 6-8) and 253 high school students (grades 9-12), for a total of 556 students. Out of the 556 students who responded, 120 were female middle school students, 48 were female high school students, 183 were male middle school students, and 205 were male high school students.

Instrumentation

This study utilized a modified instrument from the Assessing Women and Men in Engineering Project (AWE) website entitled, Pre-Activity Survey for Middle School-Aged Participants—Engineering (2009). The researcher placed each item of the original survey in a category within the Engagement, Capacity, and Continuity (ECC) Trilogy and subscales. Five national equity experts were asked to confirm the researcher's categorizing of the survey items. Each expert possessed a great depth of understanding about factors that influence females in STEM and were actively involved in systemic projects with a focus on increasing the representation of females in STEM. The experts were also asked to rank the items according to importance. The mean of the expert rankings on each item determined the top five survey items for each of the Engagement subscales (behavior, emotional, cognitive, and vocational); the four subscales were also grouped together to create the Engagement dependent variable. In order to measure whether students looked forward to science class, math class, and technology and engineering class, three additional items were added to the emotional engagement subscale. The top 10 survey items related to the Perceived Personal Capacity variable were also selected for the survey.

In order to measure the Continuity variable, the instrument required some survey items that quantified students' use of resources and participation in programs that nurtured STEM-related interests. An exhaustive list of resources and afterschool programs was given to twenty technology and engineering teachers. The teachers indicated five resources they felt their students were most likely to use and five afterschool programs their students would most likely participate in. The five resources and the five afterschool programs most frequently indicated by the teachers were added to the survey to represent the Continuity variable. One question on the original survey asked students to indicate who encouraged them to pursue engineering as a career. The researcher's dissertation committee requested that one question be divided into two separate questions so that students could identify which people outside of school and which people in school encouraged them to be an engineer.

The modified Technology and Engineering (ECC) Survey included 49 statements that operationalized the Engagement, Capacity, and Continuity (ECC) Trilogy (Jolly et al., 2004) and three demographic questions. The developer of the original instrument felt that a pilot study was not necessary to test the revised instrument because of the minor word changes and reordering of the questions. In order to verify that students could complete and read the survey with ease, 12 students who were 12-13 years old and 10 students who were 14-16 years old completed the survey. Students in each group were asked whether or not they understood what each question was asking and if something should be reworded. A group of 15 middle school students and a group of 10 high school students were also asked to complete the survey online to test ease of use and understanding online. The students in all groups reported that they understood each question on the survey.

Scoring of the Instrument

The instrument included several different types of questions. Survey items 1, 2, and 3 asked students to indicate whether they wanted a career in a technology-related field, or engineering-related field, or whether they wanted to become an engineer on a 4-point Likert scale—1 (*no*), 2 (*don't know*), 3 (*maybe*), and 4 (*yes*). Survey items 4-5 collected frequency data; students were asked to indicate who encouraged them to pursue a career in a technology- or engineering-related field. Survey items 6-23 asked students to indicate their level of interest in technology and engineering activities and work on a 4-point Likert scale—1 (*not interesting at all*), 2 (*not that interesting*), 3, (*somewhat interesting*), and 4 (*very interesting*).

Survey items 24-38 asked students to indicate their level of agreement using a 5-point Likert scale—1 (*does not apply*), 2 (*strongly disagree*), 3 (*somewhat disagree*), 4 (*somewhat agree*), and 5 (*strongly agree*). The *does not apply* was added to accommodate students who may not be enrolled in math or science at the time of the survey. In order to have a similar 4-point Likert scale as the other components in the ECC Trilogy, the responses were recoded to reflect—0 (*does not apply),* 1 (*strongly disagree*), 2 (*somewhat disagree*), 3 (*somewhat agree*), and 4 (*strongly agree*).

Similarly, survey items 39-49 asked students how often in the last year they utilized the resources and participated in activities listed—1 (*1-2 times*), 2 (*3-5 times*), 3 (*more than 5*), 4 (*have not done but would like to*), and 5 (*have not but do not wish to*). In order to include survey items 39-49 in the analysis of the *Continuity* variable, the responses were recoded to reflect a 4-point Likert scale—0 (*have not but do not wish to*), 1 (*have not done but would like to*), 2 (*1-2 times*), 3 (*3-5 times*), and (4) (*more than 5*). Survey items 50-52 were demographic questions. Students were asked to indicate their gender, grade level and the number of technology and engineering classes they have completed.

Data Collection

Prior to collecting data, authorization to conduct the study was requested from the Fielding Graduate University Institutional Review Board (IRB Protocol # 09-2340), and a subsequent modification request, submitted due to dissertation committee recommended changes, was approved. In order to survey students with similar exposure to technology and engineering, the Technology and Engineering Supervisor at the Wisconsin Department of Public Instruction was asked to recommend middle school and high school technology and engineering programs where teachers: (a) were active members of the Wisconsin Technology Education Association, (b) employed a variety of instructional strategies, (c) implemented content within their program that reflected contemporary technology and engineering curriculum, and (d) integrated engineering-related activities into their curriculum. Eight high school teachers and 6 middle school teachers were recommended to participate in the study. An email was sent to the principals of the technology and engineering teachers who were recommended to participate in the study. After permission was granted by the principal, an email invitation to participate in the study was sent to the technology and engineering teacher. Five high school teachers and 5 middle school teachers accepted the invitation for their students to participate in the study. A package that contained the consent and assent forms, survey instructions, and copies of the survey was mailed to each teacher. The survey was also available online for teachers who had lab access. Teachers mailed completed paper surveys and consent and assent forms back to the researcher.

Data Analysis

The independent variables were gender and grade level. The dependent variables consisted of Engagement, Personal Perceived Capacity, and Continuity. The dependent subscales were behavior, emotional, cognitive, and vocational engagement, as well as resources, after-school activities, and encouragement from others. A series of two-way factorial analyses of variance was conducted with the data to examine: (1) possible relationships between male and female middle school and high school students level of interest in engaging in different types of technology- and engineering-related activities and work, (2) possible relationships between male and female middle school and high school students' perceived personal capacity in technology- and engineering-related activities, and (3) possible relationships between male and female middle school and high school students in pursuing pathways created to stimulate interests in STEM fields. The data was also sorted to examine only the students who indicated they want to become an engineer. A series of two-way factorial analyses of variance was conducted with the new data set to examine students' responses within the Engagement, Perceived Personal Capacity, and Continuity variables.

Findings

When examining the Engagement, Perceived Personal Capacity, and Continuity variables separately in this study, most of the results reflect typical gender responses found in past research. Interestingly, when examining the responses of students who indicated they want to become an engineer some patterns emerged that were not gender specific and that support Jolly et al.'s (2004) ECC Trilogy. The following sections will describe the findings for each research question.

Research Question 1

The responses to survey items 6 through 28 on the survey were grouped together to form the dependent variable, *Engagement*. Statistical significance was found between genders ($F(1, 552) = 6.19$, $p = .013$, $\eta_p^2 = .011$). Males (M=3.11, SD = .48) and females (M= 2.98, SD = 50) indicated similar levels of interest in engaging in technology- and engineering-related activities and work (see Table 1). This finding coincides with past research (Weber & Custer, 2005). No statistical significance was found between genders in the behavior subscale (see Table 1); however, the means of both genders suggest that they possess a similar interest in activities that are behaviorally engaging (see Table 1).

Statistical significance was found between genders for the emotional, cognitive, and vocational subscales (see Table 1). Males indicated they possess more interest than females in emotionally engaging activities (see Table 1); this finding contradicts past research (Weber & Custer, 2005). Males also indicated more interest than females in cognitively engaging activities (see Table 1). Typically, males have prior technical and mechanical experience that females may lack (Shanahan, 2006) to complete activities in a technology and engineering classroom setting, which may impact why males find these types of activities more appealing. Not surprising, males indicated a greater interest than females in engaging in vocational work related to technology and engineering (see Table 1, next page).

Table 1
The Means, Standard Deviations, and One-Way Analyses of Variance for the Effects of Gender on the Dependent Variable Engagement and Subscales

	Females (N = 168)		Males (N = 388)				
	M	SD	M	SD	$F(1, 552)$	p	η_p^2
Engagement	2.98	.50	3.11	.48	6.19	.013	.011
Behavior	3.20	.54	3.22	.53	.14	.705	.001
Emotional	3.03	.66	3.19	.60	.57	.011	.012
Cognitive	2.96	.68	3.15	.65	6.42	.012	.011
Vocational	2.46	.76	2.73	.67	19.54	<.001	.034

Statistical significance was found between genders for eight survey items within three of the engagement subscales (see Table 2). In survey item 13, the females indicated a greater interest than males on work that helps a community; this coincides with past literature (Welty & Puck, 2000) and research (Weber & Custer, 2005). Males indicated greater interest than females in survey items 16, 20, 26, and 28 (see Table 2). However, in survey item 15, males indicated a significantly greater interest than females in work that requires repairing things (see Table 2). These findings support past research that males find technically-related activities or work more interesting than females (Mitts & Haynie, 2010; Weber & Custer, 2005). However, in survey item 17, the means for both genders reflect a lack of interest in agricultural improvements (see Table 2, next page); this again coincides with past research (Weber & Custer, 2005).

Table 2
The Means, Standard Deviations, and Analyses of Variance for the Effects of Gender for Statistically Significant Survey Items within Engagement Subscales

	Females			Males					
	M	*SD*	*N*	*M*	*SD*	*N*	*F*	*p*	η_p^2
Emotional									
13. How interesting is work that allows me to help my community or society.	3.28	.77	168	3.08	.82	388	8.87	.003	.016
26. I look forward to technology and engineering class.	2.87	1.14	168	3.32	1.00	388	16.46	<.001	.029
27. I like to learn to use computer software.	2.67	1.23	168	2.94	1.13	388	8.05	.005	.014
28. I like learning how things work.	2.91	1.21	168	3.33	.95	388	14.89	<.001	.026
Cognitive									
20. How interesting is an activity that allows me to take things apart and try to figure out how it works.	2.74	1.09	168	3.22	.88	388	29.11	<.001	.050
Vocational									
15. How interesting is work that allows me to repair things.	2.45	.97	168	3.12	.94	384	53.70	<.001	.089
16. How interesting is work that allows me to design buildings that use energy wisely.	2.48	1.11	166	2.79	.96	384	15.11	<.001	.027
17. How interesting is work that allows me to design ways to help farmers grow better crops.	2.11	.97	167	2.33	.99	387	5.33	.021	.010
19. How interesting is an activity that allows me to design things that will be used in space.	2.48	1.03	168	2.79	1.00	388	15.63	<.001	.028

Research Question 2

The responses to survey items 29-38 were grouped together to form the dependent variable, *Perceived Personal Capacity*. Statistical significant was found ($F(1, 552) = 17.00$, $p < .001$, $\eta_p^2 = .030$). Males ($M = 2.97$, $SD = .67$) indicated a higher level of perceived personal capacity than females ($M = 2.72$, $SD = .66$). However, this does not actually indicate that males possess a greater capacity in STEM than females; males just perceive that they do (Hill et al., 2010). Many survey items within the Perceived Personal Capacity variable had statistical significance (see Table 3). The mean of the male responses, for all survey items in Table 3, suggests that they perceive they possess a higher capacity in science, math, and technology and engineering than females. These findings were not surprising, as it coincides with past research (Hill et al., 2010).

Table 3
Means, Standard Deviations, Sample Size, and Effects for Survey Items with Statistical Significance within the Perceived Personal Capacity Variable

	Females			Males					
	M	*SD*	*N*	*M*	*SD*	*N*	*F*	*p*	η_p^2
29. Science is easy even when it involves math.	2.69	1.07	168	2.91	.98	387	10.64	<.001	.019
30. Science is an easy subject	2.71	1.08	168	2.91	1.00	387	5.32	.002	.010
31. Math is an easy subject.	2.65	1.20	168	2.98	1.00	385	9.17	.003	.016
32. Technology and Engineering is an easy subject.	2.72	1.07	168	3.19	.86	388	24.27	<.001	.042
33. Technology and Engineering is easy even when it involves math.	2.55	.97	168	3.02	.93	388	21.61	<.001	.038
34. Solving design problems is easy in Technology and Engineering.	2.57	.97	167	2.84	.92	388	9.29	.002	.017
36. I can use what I know to design and build something mechanical that works.	2.68	1.05	168	3.05	.88	386	23.07	<.001	.040

Research Question 3

The responses to survey items 39-49 were grouped together to form the dependent variable, *Continuity*. No statistical significance was found ($F(1, 552) = 1.25$, $p = .265$). Males ($M = 2.11$, $SD = .71$) and females ($M = 2.10$, $SD = .69$) indicated a similar use of resources and participation in afterschool activities. Survey item 42, "asked a counselor about engineering as a career," was the only survey item within this variable that was statistically significant ($F(1, 552) = 15.05$, $p < .001$, $\eta_p^2 = .027$). Males ($M = 2.20$, $SD = 1.25$) seem to feel more comfortable than females ($M = 1.77$, $SD = 1.08$) with asking counselors about engineering. Although there was no statistical significance found in survey item 48, females ($M = 2.01$, $SD = 1.18$) indicated they participated more often than males ($M = 1.84$, $SD = 1.14$) in a Science Fair. In regards to encouragement received by others to pursue engineering as a career, males (79.3%) and females (73.8%) reported being encouraged by their technology and engineering teachers. On the other hand, only 20 males and 10 females reported being encouraged by guidance counselors. In regard to people out of school, males (57.5%) reported a higher incidence of being encouraged by their parents or guardians than females (48.8%).

Research Question 4

In order to provide support for the ECC Trilogy, the dataset was sorted to only examine the responses of students who indicated "yes," they were interested in engineering as a career. Using the sorted dataset, a series of two-way between-groups analyses of variance was conducted to explore the impact of gender and school level (middle school and high school) on student Engagement, Personal Perceived Capacity, and Continuity. No statistical significance was found between genders for Engagement ($F(1, 123) = .21$, $p = .65$), Perceived Personal Capacity ($F(1, 123) = .01$, $p = .911$), or Continuity ($F(1, 123) = 1.25$, $p = .265$). However, the mean responses (see Table 4) of both genders for each of the dependent variables provide quantitative support for the ECC Trilogy. Overall, both genders indicated a high interest in engaging in technology and engineering activities and work, a high level of perceived personal capacity, and an interest in utilizing resources or participating in activities related to STEM.

Table 4
Means, Standard Deviations, and Sample Size of the Dependent Variables for Students Who Want to Become an Engineer

	Females (n = 20)		Males (n = 107)	
	M	*SD*	*M*	*SD*
Engagement	3.20	.74	3.28	.37
Perceived Personal Capacity	3.17	.85	3.27	.51
Continuity	2.10	.73	2.11	.65

Discussion

The purpose of this study was to identify whether the ECC Trilogy could be utilized by teachers in technology and engineering program setting to examine their students' interest (engagement), perceived personal capacity (capacity), and participation (continuity) in technology- and engineering-related activities. The ECC Trilogy provides a practical framework that can potentially assist teachers in identifying what factors create barriers to students wanting to become an engineer or pursuing a career in a technology- or engineering-related field. In order to identify where a lack of interest may occur, this study compared male and female middle school and high school students' responses to STEM-related survey questions that were coded to reflect each component of the ECC Trilogy.

The results within the Engagement variable provide valuable feedback for what types of activities may be interesting to both males and females. The activities completed in many STEM classrooms often foster the interests of males and deter the interests of females (Bachman, Hebl, Martinez, & Rittmayer, 2009). According to the findings of this study, traditional technology education activities that focus on technical or mechanical concepts will most likely not appeal to females, and, in turn, females will choose not to enroll in subsequent technology- and engineering-related courses (Ross, 2011). However, when technology and engineering teachers incorporate engaging, real-life activities, the interests of both males and females will be engaged (Mitts & Haynie, 2010; Weber & Custer, 2005).

Within the Engagement subscales, several findings should be highlighted. Male students indicated a greater interest in activities that are mechanical or technical in nature, which coincides with past research (Mitts & Haynie, 2010; Weber & Custer, 2005). Males often possess more experiences that have equipped them with greater technical competence than females (Shanahan, 2006); as a result, males' prior experience and greater technical competence may influence their interest level to be higher than females in mechanically-related activities (Hill et al., 2010) and in attending technology and engineering courses. Male students also indicated a higher level of cognitive interest in technology and engineering activities than female students in this study. At a very young age, males have been given more opportunities to exercise their spatial skills through manipulative toys and to excel in these types of activities (Bachman et al., 2009; Hill et al., 2010). Additionally, males in this study indicated a higher level of interest in activities that were vocationally engaging, especially when related to fixing or repairing thing, than females. Although this finding coincides with past research (Weber & Custer, 2005), the responses from this study reflect females are not interested in activities related to work or careers in technology- and engineering-related fields.

Frome et al. (2002) proposed that females keep from entering traditionally male dominated fields because females feel they do not possess strong academic ability in math, and they do not possess an interest in math and physical science. In this study, males indicated greater levels of perceived personal capacity in technology- and engineering-related activities than females; this does not necessarily mean that their capacity in STEM is greater (Hill et al., 2010). STEM fields have often been stereotyped to be masculine fields. Teachers should provide STEM-related afterschool events/activities that specifically target female students. In this study, students who reported a high level of perceived personal capacity also indicated that they participated in, or wanted to participate in, afterschool STEM-related activities or events. This finding supports the notion that if teachers create informal opportunities to strengthen students' scientific and technical skills in STEM-related areas (Katehi, Pearson, & Feder, 2009), their attitudes towards STEM may become more positive (Bouvier & Connors, 2011; Singer, 2010; Weber, 2011) and their sense of self-efficacy in engineering-related activities may increase (Bouvier & Connors, 2011; Marra, Shen, Rodgers, & Bogue, 2009; Paulsen & Bransfield, 2009).

Most females in this study did not want to become an engineer; however, they may have based their decision on stereotypes of what engineers do. Females may change their attitudes and at least consider the possibility of pursuing a career in engineering (Bouvier & Connors, 2011; Lufkin & Reha, 2009; Weber, 2011) after they participate in informal engineering-related activities that strengthen their scientific and technical skills and knowledge (Katehi, Pearson, & Feder, 2009). Past research has found that females' attitudes and interest in STEM-related fields can change as a result of their participation in afterschool activities (Paulsen & Bransfield, 2009; Weber, 2011).

Recommendations for Practice

The ECC Trilogy can be utilized by STEM Teachers to identify why females may not be enrolling in their classes. In order to engage females, teachers should examine their curriculum and implement a variety of activities that would interest both males and females. If females do not perceive that they have the capacity to be successful in STEM classes, teachers should provide learning opportunities that allow students to develop skills or acquire knowledge they perceive they do not possess. STEM teachers should become familiar with the various ways students' STEM interests are supported in the school and community and disseminate information about informal STEM-related activities or programs. STEM teachers should also provide counselors, as well as parents, with up-to-date information on the workforce needs related to STEM careers and the benefits of encouraging both males and females into these fields.

Recommendations for Future Research

This study has potential to be replicated in a number of different venues. The study could be replicated: (a) to compare responses from students who are not enrolled in technology and engineering courses with students who are enrolled in technology and engineering courses, (b) in other states or another country to see if similar findings occur that support the ECC Trilogy, (c) by teachers within their school to identify components of the ECC Trilogy that may impact female students' decisions to enroll in technology and engineering courses.

Conclusion

The purpose of this study was to operationalize Engagement, Capacity, and Continuity (ECC) Trilogy so that technology and engineering teachers can identify possible factors effecting female students' decisions to enroll in technology and engineering courses. The student responses from this study provide evidence to support the ECC Trilogy. Both female and male students who indicated that they wanted to pursue engineering as a career responded to the survey items with a high interest in the activities, the belief that they possessed a high perceived personal capacity, and an interest in participating in technology- and engineering-related areas.

Out of 388 males, only 107 (28%) indicated they wanted to become an engineer; however, out of 168 females who participated in the study, only 20 (11.9%) indicated they wanted to become an engineer. More than twice as many males than females indicated an interest in becoming an engineer. This finding should draw some concern especially with the rise in the number of individuals and organizations who invest efforts in increasing female representation in STEM (Hill et al., 2010; Lufkin & Reha, 2009; Marra, Shen, Rodgers, & Bogue, 2009). Positive influences on young people can influence their interest and success in science and math; however, the extent of the influence depends on whether the students' academic motivation, beliefs concerning their abilities, and capacity to succeed in science and math become strengthened (Larose, Ratelle, Guay, Senecal, & Harvey, 2006). Although several researchers have suggested that females may not be interested in engineering-related careers (Hill et al., 2010; Weber & Custer, 2005), STEM equity experts, teachers and post-secondary faculty must continue to collaborate efforts and share successful strategies to encourage females to enter STEM fields.

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Using CoRes to Develop the Pedagogical Content Knowledge (PCK) of Early Career Science and Technology Teachers

Research has shown that one of the factors that enable effective teachers is their rich *Pedagogical Content Knowledge* (PCK) (Loughran, Berry, & Mulhall, 2006), a special blend of content knowledge and pedagogical knowledge that is built up over time and experience. This form of professional knowledge, first theorized by Shulman (1987), is topic-specific, unique to each teacher, and can only be gained through teaching practice. The academic construct of PCK is recognition that teaching is not simply the transmission of concepts and skills from teacher to students but rather a complex and problematic activity that requires many and varied on the spot decisions and responses to students' ongoing learning needs. While much has been written about the nature of PCK since Shulman first introduced the concept in 1987 and its elusive characteristics have led to much debate, there are still gaps in our knowledge about teacher development of PCK. However, the work of Magnusson, Krajcik, and Borko (1999) is helpful in clarifying this special form of a teacher's professional knowledge by proposing that PCK is made up of five components. In their view, an experienced teacher's PCK encompasses his/her:

- orientations towards teaching (knowledge of and about their subject, beliefs about it, and how to teach it),
- knowledge of curriculum (what and when to teach),
- knowledge of assessment (why, what, and how to assess),
- knowledge of students' understanding of the subject, and
- knowledge of instructional strategies.

In recent studies of PCK (Kind, 2009; Rohaan, Taconis, & Jochems, 2010), the point is made that expert teachers are not born with PCK, and it is a lengthy process for novice teachers to acquire the bank of skills and new knowledge needed to become professional teachers who are experts in their fields. In secondary science and technology teaching, it has been argued that many graduates entering teacher education courses are unaware of the learning challenges that lie ahead for them personally, and are often naïve about and/or do not appreciate the demands that teaching will make of them (Cowie, Moreland, Jones, & Otrel-Cass, 2008; Loughran, Mulhall, & Berry, 2008). These early career teachers may not understand that effective teaching is a

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skilled and purposeful activity involving complex processes of pedagogical reasoning and action (Shulman, 1987).

Research in science education also indicates that many of these student teachers actually lack a deep conceptual understanding of their subject matter, having disjointed and muddled ideas about particular topics (Loughran et al., 2008). Interestingly, the limited research that has been done into science teachers' content knowledge around the nature of science suggests that a significant proportion of teachers have struggled with these aspects in the science curriculum (Baker, 1999) and have consequently not usually incorporated aspects of the nature of science into their teaching (Loveless & Barker, 2000). The increased emphasis on the nature of science in the science and the nature of technology in the technology learning areas within *The New Zealand Curriculum* (Ministry of Education, 2007) makes this even more of a concern. These struggles with content knowledge and the nature of science are particularly significant for secondary teachers, who were the focus of this study. As science knowledge and technological development grows apace, creating strategies to enable teachers to develop PCK around novel topics and pedagogical challenges will support success for learners in the 21st century.

Research in technology education reveals a less well-developed understanding of the role of PCK, though an international discourse does exist with studies being reported in both general design and technology education (De Miranda, 2008; Jones & Moreland, 2004; Rohaan et al., 2010; Rohaan, Taconis, & Jochems, 2009), as well as in different disciplines of technology such as Information and Communication Technology (Koehler & Mishra, 2005). While researchers like McCormack (1997, 2004) and Banks (2009) have discussed the nature of knowledge in technology education, international diversity remains a characteristic of the discourse in technology, which is an impediment to the development of PCK in the area of technology education. Consequently, one purpose of this paper is to extend this understanding through the lens of PCK, specifically the development and implementation of a CoRe in technology.

Kind (2009) identifies three common factors that appear to contribute to the growth of PCK in early career teachers. The first factor is the possession of good subject matter knowledge; the second is classroom experience, with studies pointing to significant changes occurring in the early months and years of working as a teacher; and the third is the possession of emotional attributes like personal self-confidence and the provision of supportive working atmospheres in which collaboration is encouraged.

Recently, a number of researchers in science teacher education have begun investigating and devising pedagogical approaches that help early career teachers to conceptualise their professional learning and begin laying a foundation for their own PCK development (e.g., Abell, 2008; Loughran, Berry, & Mulhall, 2006; Loughran, Mulhall, & Berry. 2004; Nilsson 2008). While there is still debate over the very nature of PCK (Kind, 2009), this new field of research offers much potential for improved teacher education, but it is problematic. For example, a key issue emerging for developers of such approaches in science and technology education has been the virtual absence of concrete examples of expert teachers' PCK, since this highly specialized form of professional knowledge is embedded in individual teachers' classroom practice (Padilla et al., 2008) and rarely articulated within the teaching community of practice. Some recent classroom-based studies in science and technology education, such as Cowie et al. (2008), have begun to elaborate on this; however, it still represents a gap in our knowledge that this research will contribute to filling.

To address the paucity of PCK exemplars in science teaching, Loughran et al. (2006) explored the PCK of highly regarded science teachers for particular topics in junior secondary science, to see if they could tease out some common threads in their pedagogy that could be considered as comprising the knowledge base of science teachers, which might be helpful to share within the profession. Loughran et al. developed a set of conceptual tools known as *Content Representations* (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) that make explicit the different dimensions of, and links between, knowledge of content, teaching, and learning about a particular topic. The CoRes, represented in table form (see Table 1) attempt to portray holistic overviews of expert teachers' PCK related to the teaching of a particular topic. They contain a set of *enduring ideas* about a particular topic at the head of the columns and a set of pedagogical questions for each row.

Table 1
Sample CoRe Matrix

Topic	Enduring Idea 1	Enduring Idea 2	Enduring Idea 3	Enduring Idea 4
Why is it important for the students to know this?				
Difficulties connected with teaching this idea				
Knowledge about student thinking which influences teaching about this idea				
Teaching procedures				
Ways of ascertaining student understanding or confusion about the idea				

CoRes have been used successfully in pre-service science teacher education to help novice teachers understand what PCK might involve and to develop their own representations of teaching in particular topic areas. In the study by

Loughran et al. (2008), a pre-service educator invited student teachers to construct their own examples of CoRes after they had examined and reflected on those created by expert teachers. The findings from Loughran et al.'s study strongly suggest that the focus on PCK using CoRes to frame their thinking about the links between science content and pedagogy did help the student teachers to gain a more sophisticated view about learning to teach science and how to teach for understanding. Another study along similar lines also sought to promote science student teachers' PCK through CoRe design (Hume & Berry, 2010). The student teachers found the task challenging, and their lack of classroom experience and experimentation proved to be a limiting factor in being able to develop CoRes successfully. However, the contribution such a task could make to their future PCK development remained a distinct possibility. In the following year, Hume scaffolded the learning prior to CoRe construction such that the student teachers could more readily access relevant knowledge when attempting such a task. Their resultant CoRes and comments indicate that with appropriate and timely scaffolding the process of CoRe construction does have the potential for promoting PCK development in novice teachers.

This developing body of literature related to teacher PCK, both internationally and in New Zealand, suggests that research into the use of expert-informed CoRes in the untested arena of PCK development by early career secondary teachers is important. Further, neither the role of content experts in the formulation of CoRes nor the analysis of resulting student outcomes when early career teachers use CoRes in their classrooms have been extensively examined. This innovative research consolidates and builds knowledge about the use of CoRes and addresses the gaps described above. Addressing these gaps in the research could help contribute to effective development of PCK for secondary teachers of science and technology, which will support success for all types of learners.

Research Design and Methodology

This research addressed the key area of early career teacher education and aimed to investigate the use of a CoRe as a planning tool to develop early career secondary teacher PCK. The study was designed to examine whether such a tool, co-designed by an early career teacher with expert content and pedagogy specialists, can enhance the PCK of early career science and technology secondary teachers. A research design was developed that incorporated a unique partnership between expert classroom teachers, an expert scientist, an expert technologist, early career teachers of science and technology, and researchers experienced in science and technology education.

This study built on nascent work by Hume and Berry (2010) into the use of CoRes in secondary teacher education. It combines the previously mentioned frameworks of Shulman (1987) and Magnusson et al. (1999) on PCK with the work of Loughran et al. (2006) on CoRes to address the development of secondary teachers of science and technology. Teachers typically enter secondary teaching in New Zealand with a degree in a specialist subject area plus one year of teacher education. These teachers then have specific content knowledge upon entering secondary teaching, such as biology, chemistry, or physics in science, and may come with a much broader range of backgrounds in technology, such as electronics or engineering. Evidence suggests that, even with this degree background, these early career teachers find it difficult to conceptualise the key concepts behind science and technology (Gess-Newsome, 1999; Loughran et al., 2008). Whilst their one year of teacher education provides some support for the development of general pedagogy, development of PCK in their specialist subject areas is limited in the timeframe available. This issue becomes more acute for early career teachers who find themselves addressing science or technology topics in their classrooms that they may not have covered well in their undergraduate degrees.

This study aimed to address this problem by researching how the development of PCK in early career secondary teachers is influenced through construction and trial of the use of CoRes in specific topics as planning tools for teaching science and technology.

Research Questions

The following research questions were addressed:

- How can experts in content and pedagogy work together with early career teachers to develop one science topic CoRe and one technology topic CoRe to support the development of PCK for early career secondary teachers?
- What differences are revealed between science and technology through the development of the CoRe?
- How has engagement in the development and use of an expert-informed CoRe developed an early career teacher's PCK?

Data Collection

This study employed an interpretive methodology using an action research approach (Creswell, 2005). It was based around a cohort of two early career secondary teachers of science and two of technology, practitioner-researchers in their second or third year of teaching. This cohort of teachers was chosen because they are just beginning to establish themselves in their profession and have some teaching experience to draw upon in planning and delivery.

Phase 1 of the study was the design of one CoRe in a science topic and one CoRe in a technology topic. These topics were brought to the research by the early career teachers as topics within which they would like to enhance their own PCK. Each CoRe was designed with the help of an expert scientist or an expert technologist who provided advice on the key ideas of the content knowledge for the topic of the CoRes and an expert secondary teacher of science and another of technology who provided advice on the pedagogical questions appropriate to address those key ideas. The experts and the early career teachers co-constructed the CoRes in a workshop situation facilitated by two of the researchers who are experienced in working with teachers and familiar with research-informed challenges in teaching and learning in science and technology.

A community of learners approach was adopted that encouraged each group member to contribute their ideas drawn from their experiences in distinct socio-historical communities of practice. This connection between different communities of practice was supported by development of an object, the CoRe, that lies at the boundary of each community (Wenger, 1998). Such boundary objects have previously been shown to bring teachers and researchers together (Otrel-Cass, Cowie, Moreland, & Jones, 2009). The workshop included instruction on the purpose and use of CoRes by the researchers. Two different researchers observed the process of construction of the CoRe to determine the nature of the contributions made by the expert scientist/technologist, expert teachers, and the early career teachers. Data were gathered using field notes during these observations of the workshop interactions, with a view to understanding how the members of the different communities work together. At the conclusion of the workshop, these observing researchers conducted short interviews with each representative group (content experts, expert teachers, early career teachers) regarding their experiences in the group and their feelings about the development of the CoRe. This addressed the first research question, which examines how the groups work together to share and co-create knowledge of how to teach a science or technology topic and, ultimately, the early career teachers' PCK. This question addressed a gap regarding expert input into CoRe development.

Phase 2 began an action research process for the teacher in partnership with a researcher. Each early career teacher who was engaged in developing the CoRe then undertook a period of planning for delivery of a scheduled unit using the CoRe as a planning tool. This planning process was reflected upon through an action research partnership with one of the researchers experienced in secondary science or technology teacher education. In this process the researcher's role was asking *why* and *how* questions of the early career teacher as they planned their unit, taking account of the CoRe. The researcher respected the planning norms of the teacher and their school and did not try to unduly influence the planning process in ways that are not consistent with the CoRe, and the unit plan constructed remained the property of the teacher. The early career teachers were asked to keep a reflective journal that recorded their thoughts about the CoRe collaborative design development process and how they used the CoRe in planning. The early career teachers discussed these reflections about their experiences in using the CoRe for planning with their researcher partner and how this contrasts with their classroom experiences from their first years of teaching in general and within the science or technology topic (Kind, 2009). Data from the reflective journals and discussions helped address the second research question. These methods of data collection stimulated recollection for the teacher and allowed for dialogic investigation of the meaning of the experiences that the teacher had through the process of planning.

Phase 3 of the study was the phase in which each early career teacher delivered a science or technology unit using the CoRe as a guide and co-researched, with a researcher partner, the outcomes of its use with one class of students. This involved observation of classroom activity by the researcher while the teacher was delivering the unit in order to promote reflective conversations in an action research process between the teacher and researcher around the teacher's delivery of appropriate and relevant content and its appropriate pedagogy, as specified in the CoRe. Three class periods, during which one or more of the enduring ideas from the CoRe is a focus for teaching and learning, were observed. Data from field notes on the three classroom observations focussed on how the teacher works with their students and how the students respond. Reflective conversations were held between the researcher and the early career teacher at the conclusion of each of these observations, and any changes the teacher planned to make in future lessons in response to their experiences in the unit were noted. A focus group interview of students was conducted by the researcher at the end of the unit to examine how the students' learning experiences may have been influenced by the pedagogical structure in the CoRe. The focus group encouraged the teenage students to share their views and experiences in a supportive manner. Data from the classroom observations and focus group interview, the teacher interview, and a final reflective conversation with the teacher addressed the second and third research questions.

Data Analysis

Data analysis was structured around the three research questions, as shown in Table 2 (next page), using an Activity Theory framework. This framework was further informed by communities of practice, PCK frameworks, and the CoRe itself, as appropriate in each phase. This occurred as follows:

Table 2
Research Summary

Research Question	Data Source	Data Analysis
How can experts in content and pedagogy work together with early career teachers to develop one science topic CoRe and one technology topic CoRe to support the development of PCK for early career secondary teachers?	Field notes from observation of the contributions and interactions within the workshop groups, and interviews at the end of the Phase 1 workshop.	Data content analysed against a community of practice framework of contributions and interactions regarding content and pedagogy for the topic.
What differences are revealed between science and technology through the development of the CoRe?	Teachers' reflective journals, classroom observations, teacher's reflective conversations,	Observations and focus group interview content analysed against a framework of content knowledge and pedagogy and each CoRe compared.
How has engagement in the development and use of an expert-informed CoRe developed an early career teacher's PCK?	Teachers' reflective journals and interview with the teacher.	Data content analysed against the five components of PCK in relation to the CoRe.

Phase 1. Data collected in this phase examined the nature of the contributions brought by each group member and the interactions between group members within the CoRe development process. Data from field notes and short interview transcripts were content analysed against a Community of Practice framework that acknowledged contributions and interactions in one dimension and content and pedagogy in a second dimension, as befitting the key components of the activity system. The outcome of this phase—the CoRe—was analysed as an outcome of the workshop activity system.

Phase 2. Data collected in this phase examined how the early career teacher and a researcher worked together in using the CoRe developed in Phase 1 to co-plan a unit of work addressing the chosen topic of the CoRe. Data from field notes, teacher reflective journals, and transcripts of reflective conversations between the teacher and researcher underwent content analysis against a framework constructed from the five components of PCK as described by Magnusson, Krajcik, and Borko (1999): (a) orientation towards teaching for that topic, (b) knowledge of curriculum, (c) knowledge of assessment, (d) knowledge of students' understanding of the topic, and (e) knowledge of instructional strategies. The outcome of this phase—the unit plan—was analysed as an outcome of the process of translating the CoRe into the unit plan.

Phase 3. Data collected in this phase examined how the early career teacher and their students experienced a unit delivered on the topic of the CoRe. Data from field notes from the three classroom observations and the student focus group interview were content analysed against a framework of content knowledge and pedagogy derived from the CoRe. The student pre- and post-unit questionnaires were analysed for evidence of understanding of the enduring ideas of the topics as determined in the CoRe by the use of descriptive statistics. The final teacher interview was content analysed using the framework of the five components of PCK, as described by Magnusson, Krajcik and Borko (1999), in relation to the CoRe to triangulate the student data by examining the extent of development of the early career teacher's PCK for their classroom practice. The outcome of this phase was then analysed as an outcome of the process of delivering the unit using a CoRe-designed unit plan. Analysis of the workshop data in Phase 1, the interview and journal data in Phase 2, and the observation and interview data in Phase 3 was carried out by the researchers. Findings were collated and presented to the whole research team for interpretation and discussion in a second one day workshop. The relationship between the research questions, the data source, and the data analysis is represented in Table 2.

The CoRes

Appendices 1 and 2 show the CoRe that was developed by the technology teachers (Appendix 1) and the CoRe that was developed by the science teachers (Appendix 2). This was the outcome of the first workshop and was used as the basis for the early career teachers to plan their unit of work.

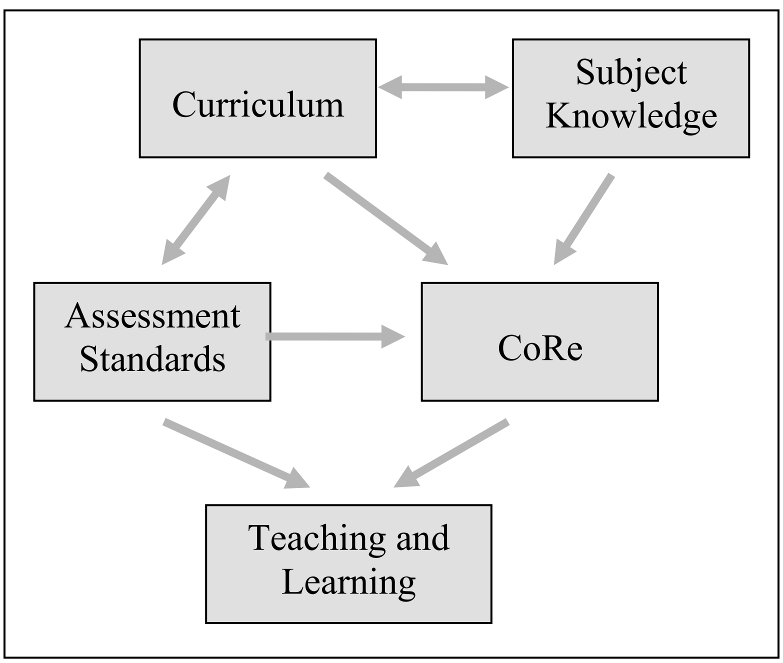
Quality Assurance

Quality assurance in this research was enhanced in a number of ways. First, multiple perspectives from several communities of practice that are related to classroom teaching and learning were provided by engagement of all team members in the process of CoRe design. Second, prolonged engagement between the researchers and the teachers through the unit planning and delivery phases, triangulated by reflective conversations and the teachers' reflective journals, provided a sound picture of the teachers' experiences of planning using the CoRe. Third, the influence of the CoRe during the teaching phase was examined through observation, questionnaires, and interviews. Fourth, student questionnaires and focus group questions were piloted for validity; teacher interview questions were peer-evaluated and piloted where feasible; and all individual interview transcripts were participant-validated. Finally, preliminary themes and findings from the data were discussed by the whole research team, ensuring that multiple perspectives from several communities of practice were brought to bear in the interpretation of the data.

Findings

The content and pedagogy experts generally worked constructively with the early career teachers (ECTs) in designing their CoRes. The ECTs noted that they highly valued the input of the experts and felt that the design process had enabled them to identify and access the knowledge about the key concepts of the topic, as well as learn new pedagogical techniques for delivering particular content material. All the ECTs reported that they felt that being involved in discussions with the experts in the construction of the CoRe helped them to understand the big picture of the topic. Although the teachers kept in mind the needs of the curriculum and assessment through these discussions, they felt that the CoRe discussions were somewhat liberating in allowing exploration of what the topic itself was all about. Figure 1 below illustrates how the research team saw the connections between the CoRe and other influences on teaching and learning at secondary school level.

Figure 1
Model of how a CoRe might fit in senior secondary schooling.



There was a marked difference between the way the science group and the technology group approached their workshop task of developing the conceptual enduring ideas for the CoRe topics of Organic Chemistry and Materials Technology respectively. The science group much more quickly developed a consensus about the enduring ideas because they already had in mind a common idea of what was important for this topic, developed from text book and curriculum agreement, and so the discussion involved simply deducing from this agreed list which ones they wanted to include in the CoRe. In the technology group, there was a sense of developing the list of potential enduring ideas from first principals; consequently, there was far more negotiation and justification in the workshop leading to the development of agreed enduring ideas. There was no schema that was familiar to all the workshop participants that could provide a common starting point, with the teachers tending to come from a curriculum perspective and the experts deriving their schema from a more disciplinary origin. Consequently a lot more of the workshop time was spent by the technology group coming to agreement on the enduring ideas.

In the case of science, the process of choosing the topic was relatively unproblematic. An initial choice was made to move from science to the subset of chemistry, and then, within that, the area of Organic Chemistry was selected as the topic for the CoRe. In the less structured epistemology of technology, Materials Technology was selected as the topic, a second tier level of knowledge organization. It may be the case, that had a third tier area been selected as the topic (for example Composite Materials), as was done in science, the more narrow subset may have resulted in less discussion and debate and a faster resolution in agreeing to the enduring ideas of, say, Composite Materials Technology.

There was a variety of teacher response to using the CoRe in their planning. For one chemistry teacher, the CoRe encouraged her to change the teaching sequence within the topic to focus on students learning some fundamental knowledge, which she felt paid off when she considered the students' overall learning outcomes. For the second chemistry teacher, the CoRe design process encouraged her to focus more on relevant examples to illustrate how the topic was important in students' daily lives. The teacher found this stimulating, and the students enjoyed learning about these examples, but the teacher noted a need for resources that provided more real-world applications of the chemistry topic that she could readily access for teaching. For the technology teachers, the CoRe encouraged them to weave more conceptual thinking into their lessons, something that the students found a little difficult, as they were more used to focusing on practical skill development. However, the teachers felt that the additional conceptual thinking would help the students understand more of the fundamental ideas behind materials technology, which they would be able to transfer to future projects.

The immediate usefulness of the CoRe seemed to lie in different areas for technology and science. The science ECTs seemed to get the most benefit from seeing the need for, and developing with confidence, examples of organic chemistry in authentic contexts to support the theoretical understandings they were focussing on developing with their students. In technology the ECTs saw the immediate benefit in quite the opposite way. For them the opportunity to see the big picture of Materials Technology, to articulate its theoretical underpinnings and consequently development of a philosophy that was conducive to a rational epistemology, was perceived to be the main benefit. What followed from this was a more thoughtful approach to developing lesson content by the ECTs, as evidenced by the introduction of a range of different pedagogies and teaching resources. Whereas, in the absence of the CoRe, the technology teachers would just teach those aspects of materials technology that the students needed to complete their current project.

The application of the CoRe to a teaching unit was different in science and technology. In science, the chemistry CoRe was truly a content representation, dealing with a discrete and contained unit of work that was treated as such by textbooks and was aligned with the curriculum for this year level. In technology, the Materials Technology CoRe had to be contextualized within a project, which permitted the application of the content. So it was not a self contained content representation, but rather a topic that could be applied within a project context.

The practical/theoretical dichotomy was an aspect of both the science and technology teacher's implementation of the CoRe, but in opposing ways. The science teachers noted that after an examination of, and through discussion of, the pedagogical questions related to the content ideas in particular, they had a deeper understanding of the importance of engaging in practical activities in order to assist students understanding of the relevance of the topic. The reverse outcome was the case for the technology teachers. After the realization of the need for a conceptual framework prior to determining the enduring ideas for the topic during the first workshop, the teachers felt that students also needed a broader framework of understanding than their immediate and felt needs related to the completion of their current project. Consequently, during the implementation of the CoRe, the teachers planned for more classroom activity than they normally would in order to provide this framework for the students and to spend time generalizing from the specifics of their current project to broader principles that could be applied elsewhere. A number of students indicated that they did not appreciate this provision, reflecting their belief that the main reason for their being in class was to get on with building something.

CoRes have been traditionally developed in the context of science education, and most research since has been in the context of science. The questions typically used in a CoRe relate to the nature of scientific knowledge and the pedagogies of science education. The differences between science education and technology education have been elaborated elsewhere, and this research has indicated that the questions generally used in a CoRe may not be appropriate in assisting to enhance technology teachers PCK.

In the context of a CoRe, the differences between that nature of technological and scientific knowledge have not been considered by research. Relevant technological knowledge is defined by its usefulness to the task at hand. If it does not help to achieve a specific goal, then it is neither useful nor relevant and so can be discarded. Consequently, it is difficult to predetermine what technological knowledge is relevant because problems that may arise in the pursuit of a technological goal cannot be anticipated. So the notion of designing a CoRe in the current format and using that as the basis for the design and implementation of a unit of work in technology is fraught.

An additional and related issue in the implementation of a CoRe in technology education as a means of enhancing a teacher's PCK is the importance of both conceptual and procedural knowledge. Vincenti (1984) describes conceptual knowledge as explicit, the theory of technology. Procedural knowledge is the often tacit driver of decision making and relates to appropriate decisions made through designing, problem solving, modelling, testing, and planning. Parayil (1991) interestingly characterizes this tacit knowledge as papyrophobic in nature, admittedly less so as time goes on, but maybe still recognizable in many technology classrooms. The early career technology teachers in this research highly valued procedural knowledge, but this was not really elaborated in the CoRe, which is why they felt they had to re-contextualize what had been developed in the first workshop.

This highlights a question related to the applicability of the standard CoRe questions to the subject area of technology. Are these the best questions, given the nature of technological knowledge, for teachers to consider in developing their PCK? The questions are:

- What do you intend the students to learn about this idea?
- Why is it important for students to know about this?
- What else do you know about this idea (that you do not intend students to know yet)?
- Difficulties/limitations connected with teaching this idea.
- Knowledge about students' thinking that influences your teaching of this idea.
- Other factors that influence your teaching of this idea.
- Teaching procedures (and particular reasons for using these).
- Specific ways of ascertaining students' understanding or confusion around this idea.

The assumption has been, in the application of CoRes to the area of science, that the enduring ideas relate mainly to conceptual knowledge. In an application to technology, the ideas need to be reflective of both procedural and conceptual knowledge. The integration of this knowledge in a technology CoRe could also assist in overcoming the common dichotomy between theory and practice in technology, by having questions that consider both in an integrated way.

Implications of Study

Teacher professional development and learning. This study has indicated that CoRes developed in this way have potential for helping ECTs access content experts' and expert teachers' knowledge and experience. Our findings revealed a willingness for the experts to be involved in the CoRe process, and that they felt that they gained a better understanding of the challenges that beginning teachers face in teaching their subject. Both the experts and the ECTs enjoyed the opportunity to discuss the key concepts and the ways to teach them. There was evidence that the mutually informing outcomes of these discussions represented a worthwhile investment of time for all parties concerned. However, it was also clear that to create space for such a design process outside of a funded research project would require time commitment and innovative ways to collaborate between ECTs and experts.

This leads to consideration of how all ECTs can benefit from being involved in CoRe design with experts across a variety of learning areas and topics. Whilst participants in this project clearly appreciated the opportunity to work face to face with experts, it would seem unlikely that this opportunity could be provided for all ECTs in all learning areas. A potential solution to this dilemma may be the use of electronic media. Applications such as Wikis or e-portfolios via computer are already being used as collaborative workspaces in many areas of education. Bringing together a group of ECTs and some experts in a virtual space may allow for collaborative but asynchronous (and therefore time-flexible) development of CoRes. This has potential for involvement of greater numbers of ECTs in a cluster, and also facilitates consideration of the ongoing evolution of a CoRe as ECT PCK develops. This latter idea is important, as development of PCK should not be seen as reaching an endpoint. Indeed, in this study, it would be of interest to return to our ECTs in years to come to examine how their PCK had further developed and what a revised CoRe of the same concept might then look like.

The nature of CoRe design and PCK in different learning areas. A further implication of this study arose from the unsurprising finding that the nature of each learning area is different, for example, in this study between science and technology. These differences were manifest in the historical conceptual thinking underlying the learning area, the way that the subject is taught, and the traditional backgrounds of the teachers in those subjects. These differences raise implications for the design of CoRes in different learning areas. The original CoRe structure was designed in science, and whilst the technology teachers were able to work with the CoRe structure, there was some debate at the end of the project as to whether the set of eight pedagogical questions might be the most appropriate ones for all learning areas. Further research into the use of CoRes in other learning areas would help to respond to this question.

The concept of the content area or topic that a CoRe refers to is relatively unproblematic in Science. Science has a well-established epistemology, leading to an established organisation of knowledge into accepted topics of inquiry. Technology on the other hand has a shorter history of study as a philosophical enterprise and no commonly agreed upon epistemology. Robust debate still exists about the nature of knowledge in technology and the way knowledge empowers technological practice. The results of this research indicate that as the concept of CoRe design is widened to incorporate teaching and learning in areas other than science, what is considered to be a content area or topic within that learning area may need to be considered carefully.

A concern that arises from this research is its scalability. It would not be logistically nor economically feasible for teachers to be engaged in day-long workshops with experts to develop CoRes for use in their teaching as a way to enhance their PCK. It may be possible to use electronic means to facilitate broader consultation, and this research team is developing a proposal to test this notion.

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Appendix 1: Technology Education CoRe

Materials Technology (Year 11)			
	Enduring ideas		
Pedagogical Questions	**The structure of materials determines its behavior.**	**The structure of materials determines the best processing techniques for making products**	**Design decisions are informed by knowledge of materials properties**
What you intend the students to learn about this idea	Material structure determines its functionality and suitability for a given purpose. (Brick wall analogy) Behavior – mechanical, chemical, etc. Composite materials – designed to produce new properties	By applying techniques, you can alter the structure or shape of the material. Main groups: moulding, joining, extrusion, cutting/machining,	Design requirements are met by a combination of material properties and shape.
Why is it important for students to know about this	To help them make informed decisions for material selection. The select the appropriate materials for a specific purpose.	So students can successfully complete their functional projects.	This allows the consideration of a number of viable options.
What else you know about this idea (that you do not intend students to know yet)	Bonding types, atomic structure, importance of defects.	Advanced processing techniques, TIG welding, steam bending, thermal evaporation, laser cutting, rapid proptotyping.	Failure analysis, factor of safety calculations
Difficulties/limitations connected with teaching this idea	Students see relevance. Nature of school facilities Prior course experiences Assessment structures (e.g., ITO's)	Access to equipment, health and safety requirements, student preconceptions (e.g., wood, saw, and nails. Diversity of projects/contexts (e.g., 20 different projects in the one classroom)	Lack of knowledge and experience of materials by students. Lack of design knowledge, modeling, testing, visualization.
Knowledge about students' thinking which influences your teaching of this idea	Misconceptions related to terminology – stress, strain, stiffness, toughness, sustainability.	Previous curriculum experience. Background experience with tools and equipment. Materials choices based on prior experiences.	Maths ability, science knowledge, academic ability to understand concepts. Range of student ability. Differentiated learning.
Other factors that influence your teaching of this idea	Attitudes of staff and the rest of the school.	Intermediate school experiences and what goes on there.	Access to materials. Cost. Time. Equipment. Computer, internet.
Teaching procedures (and particular reasons for using these to engage with this idea)	Demonstrations, relevant examples. Across the spectrum of materials. Hands on. Models (plasticine, spaghetti, chocolate)	Hands on after instruction. Experimentation. Activity to teach a concept.	Industrial examples of how people do this. Evaluating examples, deconstruction; physical/cognitive. Videos, uTube segments. (e.g., electric fence).
Specific ways of ascertain students' understanding or confusion around this idea (include likely range of responses)	Whether the product they design is fit for purpose Evidenced in context, design decisions that are made and their justifications.	Whether the product they design is fit for purpose Evidenced in context, design decisions that are made and their justifications.	Whether the product they design is fit for purpose. Evidenced in context, design decisions that are made and their justifications.

Appendix 2: Science Education CoRe

Organic Chemistry (Year 12)					
	Enduring ideas				
Pedagogical Questions	**Organic compounds are named and drawn using the IUPAC system**	**Functional groups control the reactivity of an organic compound**	**The physical and chemical properties of a substance are determined by its structure**	**Organic chemistry allows us to meet society's needs, resolve issues, and develop new technologies**	**Experimental investigations help chemists understand properties**
What you intend the students to learn about this idea	Functional groups (names and formula and how to convert between) Names (of compounds with 1-8 carbons) – prefixes and suffixes Number, substituent and parent name Molecular and structural formula incl. condensed	Different patterns of reactivity of those functional groups specified in Year 12 achievement standard	Isomerism – structural and cis/trans Properties of naturally occurring molecules Homologous series – trends as C chain increases Markovnikov's rule	Anesthetics, fumigants, polymers e.g .PVC, petroleum, distillation esters, breathalysers, solvents, vinegar etc	Molymods (3D models). Reflux and distillation. Separation.
Why is it important for students to know about this	Is the basis of organic chemistry a systematic approach that enables logical thought? Terminology is accepted internationally – enhances scientific literacy and communication.	A fundamental concept of organic chemistry. A way of categorizing the reactions of organic compounds – can predict the behavior of a substance.	Leads to an ability to understand other forms of isomerism and to predict reactions with molecules of different chain length and functional groups	Organic chemistry can both help meet society's needs and create issues to be resolved. Relevance and purpose – being able to make informed decisions over use of chemicals.	
What else you know about this idea (that you do not intend students to know yet)	Other functional groups (e.g., amides) Names of molecules with more than 8 carbon atoms	Reactions of other functional groups not included here (e.g., secondary/tertiary alcohols, alkanes with epoxides, etc.)	Optical isomerism and E, Z isomerism	Condensation polymerization. Student dependent and time dependent. Development of illegal substances	
Difficulties/limitations connected with teaching this idea	Some compounds have common names that can confuse students (e.g., acetic acid). Another language to learn (hard for ESOL), and lots of terms that are similar.	Being able to correctly identify the functional group amid so many different reactions. Tendency to compartmentalize learning and not make links to other learning. Learning other reactions that are involved.	3D spatial awareness of isomers. Lack of models	Teacher lack of knowledge of real world – not easy to find information. Research of information takes time.	

Appendix 2: Science Education CoRe (Continued)

Knowledge about students' thinking which influences your teaching of this idea	Understanding the conventions of structural formula. Prior experience/knowledge of some everyday organic compounds (e.g., octane)	Their knowledge of acid-base reactions Links to everyday contexts Their knowledge of redox reactions possibly	Limited experience of 2D and 3D thinking (e.g., rotation of bonds)	Interests of students – boys/girls. Answer to "Why do I need to know this?"	
Other factors that influence your teaching of this idea	Availability of Molymod equipment for visualization Need for kinesthetic activity	Having classroom wall space for reaction maps	Difficulty with spatial thinking – possibly more so in girls	Answer to "Why do I need to know this?" The enjoyable part of teaching and learning.	
Teaching procedures (and particular reasons for using these to engage with this idea)	Starting from parent alkane and scaffolding from there – building up with functional groups Verbalising names for reinforcement Model building, YouTube clips and animations	Illustrative experiments, video clips, reaction maps, class notes, animations, role plays	Animations to show rotation of bonds Molymods – manipulation Carry out reactions with actual substances	Popular music with chemistry messages. Student inquiry. Video clips, news stories	
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	Naming given organic compounds Questions, assignments, peer assessments, BestChoice – mastery, card games, dominoes, mix n match	Naming given organic compounds Questions, assignments, peer assessments, BestChoice – mastery, card games, dominoes, mix n match. Use of models, role plays	Naming given organic compounds Questions, assignments, peer assessments, BestChoice – mastery, card games, dominoes, mix n match. Use of models, role plays.Identify structural formula for a given molecular formula	Identify fallacious chemical examples of advertising Develop questioning disposition Debates	

Analysis of Five Instructional Methods for Teaching Sketchpad to Junior High Students

This manuscript addresses a problem teachers of computer software applications face today: What is an effective method for teaching new computer software? Technology and engineering teachers, specifically those with communications and other related courses that involve computer software applications, face this problem when teaching computer software designed to assist in graphic design, web design, programming, robotics, etc. The question of what instructional method would prove most effective is one that affects not only teachers but also IT trainers, as computers and computer software applications continue to be the primary tools of work and leisure. Despite the increase in computer software application use, the associated literature on instructional techniques used to teach computer software is inconclusive in regard to which instructional methods are the most appropriate for teaching new software, especially in junior high technology and engineering classrooms.

This study was designed to help identify best practices for teaching a new computer software application to junior high students. Five commonly used instructional techniques by technology education teachers were used to teach a new computer software, Sketchpad, to various samples of junior high technology education students.

Related Literature

A review of literature related to technology teaching, software application instruction, instructional methodologies, and other related topics was performed as part of this research study. However, because the focus of this paper is to describe and analyze teaching a new computer software application to junior high students using five different instructional methods, the literature review will focus on a description of the five instructional techniques used in this study.

Instructional Methods

Throughout history, there have been many instructional methods documented (Egal, 2009). The literature associated with technology education reveals five commonly used, cited, and recommended instructional methods. These methods include: (1) *direct instruction*, (2) *problem-based learning*, (3) *video-based tutorial learning*, (4) *cooperative/collaborative learning*, and (5) *book/written script tutorial learning*.

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Direct Instruction

Direct instruction, a term first coined by Rosenshine (1976), is a teacher-centered instructional method (Schuman, 1998) that typically follows a process in which teachers present new information followed by classroom activities that incorporate structured, guided, and independent student practice. While many research studies have found direct instruction to be an effective instructional strategy (Bock, Stebbins, & Proper, 1977), the recent push towards hands-on, student-centered curricular activities has resulted in direct instruction becoming less popular with many teachers (Magliaro, Lockee, & Burton, 2005).

Problem-based Learning

Problem-based learning is an instructional strategy in which problems form the organizing focus and stimulus for student learning. Distinguishing features of problem-based learning include teachers accepting the role of facilitators and students assuming major responsibility for their learning as they engage in problem-solving activities. Students are typically presented with problems and then work in small, self-directed learning groups to investigate and develop solutions to given problems (Barrows, 1996). While problem-based learning can be difficult to implement in the classroom (Liu, 2004), benefits from problem-based learning include development of higher-level thinking skills (Duch, 2001), long term content retention (Norman & Schmidt, 1992), better attitudes toward learning, higher motivation (Albanese, 1993; Norman & Schmidt, 1992), and the development of students problem solving skills (Gallagher, 1997; Hmelo & Ferrari, 1997).

Video-based Tutorial Learning

With the popularity of computer-based instruction, video-based tutorials as a means to learn various software programs have become commonplace as is evidenced with a quick YouTube search of most major software programs. The perceived advantage of this instruction method is that students are able to watch, review, and utilize lesson recordings in whatever manner best suits their educational needs. Some studies have reported positive findings in relation to video-based tutorials, reporting a greater ability for students to construct, or discover, their own knowledge (Bork, 2000) or that foreign students with weaker language skills prefer Web-based tutorials to traditional class lectures (Sweeney & Ingram, 2001). However, Merino and Abel (2003) reported findings, which are consistent with other studies, that there was no statistical significant difference in student learning when comparing video tutorials and traditional lectures.

Cooperative/Collaborative Learning

In a cooperative or collaborative learning structure, students work in small groups to accomplish a task and are usually rewarded based upon the performance of the group. Deutsch (1962) first conceptualized the three types of interpersonal goal structures that are typically used in classrooms: cooperative, competitive, and individualistic. These goal structures specify the type of interdependence that exists among students as they strive to accomplish learning goals. While many teachers agree that there is a time in which each of the goal structures should be appropriately used, research (Johnson, & Johnson, 1995) indicates that students participating in cooperative learning environments perform as well or better than students in competitive and individualistic learning environments on measures of achievement and attitudes toward learning.

Book/written Script Tutorial Learning

In typical text tutorials, students are expected to read the text, answer key questions posed to them in the text, and retain the knowledge for future use. The addition of images, graphs, and iconic cues has increased the effectiveness of textbook learning (Winn, 1987; Kamil, 2010; Guri-Rozenblit, 1988).

Methodology

This study included using each of the instructional techniques described above to teach a new computer software, Sketchpad, to a sample of technology education junior high students and then analyzing the impact that each technique had on student learning by giving them an assignment to use Sketchpad to design a CD cover of a band or artist of their choice.

Students

The students in our study were between the ages of 11 and 13 and were registered in a public junior high school 7th or 8th grade Intro to Technology class. Intro to Technology is part of the Utah CTE (Career and Technology Education) core classes that are designed to introduce students to technology and allow exploration of technological systems and their impacts on society (Utah State Board of Education, 2010). Demographic information such as grade point average, socioeconomic status, computer experience, and computer-based multimedia program experience was collected. This information was used to ensure that the sample size was homogeneous.

Teachers

Schools and teachers were selected because teachers had a similar number of years teaching, facilities were comparable, student demographics were similar, and teachers had multiple periods of the Intro to Technology course. Each teacher was assigned one of the methods identified in the literature review as the method of instruction to use when teaching the new program to the students. Teachers were asked to adhere strictly to their assigned instructional method while involved in this study. Teaching styles were assigned randomly to teachers who were provided an explanation of the teaching style, definitions, examples, outlines, and associated procedures as a guide for their teaching experience. The authors recognize that there may be a reliability issue or limitation in assigning and expecting a teacher to properly use the assigned teaching style. However, video recordings of the teacher using the method were made and later analyzed by three education professors who verified that the teaching methods were appropriately implemented. Teachers were provided with cameras and recorded for approximately 90 minutes. Teachers positioned the camera such that the majority of the class was visible and teacher-student interactions were captured digitally. This verification process helped reduce this limitation.

Software Program

The software program to be taught needed to be new and unfamiliar to all student participants. Sketchpad is an online image creation and editing software developed by Mugtug, an online community dedicated to the development of free online programs for image editing and creation. Sketchpad was chosen because it: (a) is a program similar to other image-editing programs typical to the multimedia industry; (b) is advertised as easy to use; (c) has buttons, effects, and options similar to other multimedia programs; and (d) has a relatively small number of tools and options, which provided for a smaller learning curve. Sketchpad is a strictly online program, requiring no download, and allows for an easy download of the finished product upon completion.

Prior to the study, it was confirmed that this software had never been taught to the student participants. The software was taught for two 90-minute class periods. Although some might argue this is insufficient to establish a cause and effect relationship between instructional methodology and the outcome, this time allotment was appropriate for this study, as it fit within the typical amount of time that each teacher reported they used for introducing software. For example, in the reporting of the demographic information, each teacher reported that they usually spend 1-2 class periods (60 minutes each) introducing the basics of a software. Concerning this, one teacher clarified, “I usually spend only 1-2 classes teaching the students the basics of the new tool (ex. Adobe Illustrator), and then in following classes, students work on their projects using the tool. I find a brief intro suffices for my students.”

Data Collection

Data was collected in multiple ways: (1) students and teachers completed a survey regarding their perceptions of the effectiveness of different types of instructional methods, (2) teachers were video recorded while teaching the software (Sketchpad) using the assigned method of instruction, (3) students created a CD cover for an artist or band of their choice using the program taught in class, and (4) student work was graded by a panel of 20 graders. The panel consisted of students and professor from a college-level graphic design course. The average grade of each product was used as the reported data point.

Surveys

Students completed a Likert-based survey prior to creating the CD cover. The survey questions included items such as: How much experience do you have with multimedia programs on the computer? How familiar are you with computers?

One key element of the self-report survey was asking students what they believe is the most effective method for teaching a new computer software application. Students were given options and definitions for each method of instruction. Students were asked to differentiate effectiveness of teaching methods for themselves and for their classmates. Students were also asked to identify the method that they perceived the teacher in their class used most frequently.

Teachers also completed a survey prior to teaching the students. The teacher survey consisted of 20 questions about issues regarding teaching experience, class size, technology equipment use, teaching style, education, and multimedia program experience. Teachers were asked to answer each question while considering only the specific class the study was being conducted in. These responses were analyzed to ensure that teachers were similar and that each teacher had a broad base of technology education experience to draw from.

Teachers were also asked to identify personal tendencies, preferences, and effectiveness in using different methods for their classroom. Teacher responses were compared with student responses to determine what relationship teacher–student perceptions have in regard to instructional methods.

The teacher survey also contained questions relating to their students' grade point average, socioeconomic status, computer experience, multimedia program experience, and average class assignment grade. These results were cross-analyzed with similar questions posed to students to verify data validity and reliability. These results also helped ensure that items such as student computer experience and average grade on assignments were comparable for different classrooms involved in the study.

Classroom Instruction

Each teacher was assigned an instructional method to teach Sketchpad. Teachers were provided with a definition of the method of instruction and asked to strictly adhere to this method of instruction. Teachers introduced the assignment to students, introduced the associated rubric, and gave the students a timeline for completion. Teachers were given a copy of the rubric outlining how the final CD covers were to be graded. Teachers then taught Sketchpad to the students. Each teacher completed the study during the course of two class periods (90 minutes), while video recording the instruction.

Teachers video recorded themselves while teaching. The video recordings were watched by three education professors who used a specific rubric to ensure that the assigned teaching techniques were indeed the actual technique used. The professors unanimously reported that there were no deviations.

Student Assignment

Students were given the grading rubric and description of the assignment before working on the computer. Then students were taught SketchPad before they did the assignment. Students were given 60 minutes to produce the CD cover either by themselves or in a group, depending on the assigned method of instruction. As part of the study, students were informed that their participation in the survey and study would have no impact on their grade. Student work was graded at a later date according to the provided rubric by a panel of graders with design background.

Grading

Twenty students and a professor from a college-level design course graded the student work. Graders received a copy of the rubric and assignment instructions to assist them in grading. Each student-produced CD cover was assigned a grade on a Likert scale from 1-5 by each of the graders. Graders were blind to the student name, class, and instructional method. Student scores were compiled from each grader, and an average score for each student and then each class was obtained. The average grade received by students from each class was compared with the instructional method used in that class in an attempt to identify effectiveness of each method.

Data Analysis

Student demographic information was analyzed to ensure similar populations, similar familiarity with technology and computers, and similar experience in multimedia classroom settings. The average scores for student work in each class was collected and compared with the method of instruction provided, resulting in an average score for each method of instruction. Additionally, surveys for teachers and students were collected and cross-analyzed. The student's perceptions of methods used in the classroom were compared with the methods identified by the teachers in an effort to identify similarities and disparities in perceptions of instructional methods. Data was aggregated for statistical analysis. Two specific measures of significance were performed with regards to the data—a *t*-test and an effect-size test. Although the authors believe the *t*-test and effect-size test were appropriate for this study, they recognize that statistical power is directly related to sample size. Because the sample of this study was limited to 87 student participants, the authors believe the findings are limited to helping create only an understanding regarding teaching Sketchpad to 7-8th grade junior high technology education students, but is not telling for a larger population. Consequently, additional research should be done to further corroborate these findings.

Findings

The most prevalent findings of this study are: (a) teachers and students have different perceptions about the effectiveness of different instructional techniques, (b) teachers and students have different perceptions regarding frequency of use of instructional methods in class, and (c) student perceptions of higher instructional effectiveness did not correlate with higher grades received for the assignment.

Student and Teacher Perceptions about Effectiveness of Instructional Techniques

There is a disconnect between what teachers and students perceive as effective instructional techniques: (1) students perceive book learning to be the most effective method of instruction for themselves and their classmates, and (2) teachers perceived direct instruction to be the most effective method of instruction and book learning to be the least effective method of instruction.

Student Perceptions

Students perceive book learning to be the most effective method of instruction for themselves and their classmates, ranking book learning above all other forms of learning in effectiveness for their classmates' learning (Table 1). The variance between responses showed statistical significance (t = 2.57, 4.01, 4.06, 3.6).

Table 1
Student Ranking of Effectiveness of Instructional Methods for Their Classmates' Learning

Instructional Method	Mean Score
Book/Written Script Tutorial Learning	3.04
Problem-Based Learning	2.76
Direct Instruction	2.63
Collaborative Learning	2.57
Video-Based Tutorial Learning	2.55

The difference between the two highest ranked methods (book learning and problem-based learning) was .28 (3.04-2.76), suggesting statistical significance (t = 2.57). This means that students not only perceive book learning as most effective for their classmates but the gap between book learning and the next most effective method (problem-based learning) is significant—suggesting an important difference for respondents between the effectiveness of each method of instruction (Table 2).

Table 2
Statistical Analysis of Student Ranking of Instructional Methods for Their Classmates' Learning

Data Sets Compared	Mean	Std. Deviation	t	d	r	r^2
Book/Problem-Based	3.04; 2.76	1.285; 1.02	2.57	.24	.12	.014
Book/Video	3.04; 2.55	1.285; 1.33	4.01	.37	.18	.032
Book/Collaborative	3.04; 2.57	1.285; 1.19	4.06	.38	.19	.032
Book/Direct	3.04; 2.63	1.285; 1.148	3.6	.34	.17	.029
Problem-Based/Direct	2.76; 2.63	1.02; 1.148	1.28	.12	.06	.003
Problem-Based/Video	2.76; 2.55	1.02; 1.33	1.90	.18	.09	.008
Problem-Based/Collaborative	2.76; 2.57	1.02; 1.19	1.83	.17	.09	.008
Video/Direct	2.55; 2.63	1.33; 1.148	.69	.06	.03	.001
Video/Collaborative	2.55; 2.57	1.33; 1.19	.17	.02	.01	.0002
Direct/Collaborative	2.63; 2.57	1.148; 1.19	.55	.05	.03	.001

When book learning was compared with each of the other identified teaching methods, it was the only method to show statistical significance in the average mean difference in every comparison (i.e., book learning compared with video tutorial learning, book learning compared with direct instruction, and so forth). No other method had such statistical significance.

Several possible reasons could be cited for this perception. First, books often include images, graphs, screenshots, step-by-step instructions, and other tools that may assist the learning of a new computer software application. Although video tutorials can provide similar media content, books allow students the ability to tangibly hold the instructional material and go at their own pace of learning. A book can be easily consulted for questions and can help the reader to access needed information quickly and repeatedly if needed (Kamil, 2010).

Second, it is possible that student perception is skewed by the common practice of book learning, and students simply assume that book learning is the best way because that's what they perceive most of their teachers use. Up through and including junior high, textbooks are the "primary mediator of learning" for students in and outside of the classroom (Kamil, 2010).

The third possibility for this finding is that, developmentally, junior high students are not quite ready to be self-learners (where they no longer need as much teacher-led learning). In Perry's (1970) theory of intellectual and moral development, Perry states that students begin their development "trusting authority figures" at a young age, but they later seek to know the "right answer" on their own as they mature. At the junior high level, students are still in the very beginning stages of intellectual and moral development, which may be the reason students perceive book learning as so effective—it's a built-in authority figure that they can reference whenever needing to find the "right answer."

Students were also asked to identify the effectiveness of instructional methods for their own learning. Although learning styles were not taken into account in this research study, this question did allow students to independently identify which method(s) of instruction they believe is (are) most effective for their own learning. Students were not instructed to think about any one particular class or subject in reference to this question.

Students reported that they believed book learning is the most effective method of instruction for their own learning (Table 3). Similar to the previous question, students were not asked what method of instruction they preferred, but rather what method of instruction they perceive as most effective for their own learning. The difference in average scores of effectiveness for book learning when compared with each other method was statistically significant (t = 2.64, 4.54, 3.17, 2.93). Additionally, when compared for educational significance (Table 4, next page) each variance for book learning compared to other forms of learning showed educational significance (d = .25, .43, .3, .27).

Table 3
Student Ranking of Effectiveness of Instructional Methods for Their Own Learning

Instructional Method	**Mean Score**
Book/Written Script Tutorial Learning	3.02
Problem-Based Learning	2.71
Direct Instruction	2.66
Collaborative Learning	2.63
Video-Based Tutorial Learning	2.45

Table 4
Statistical Analysis of Student Ranking of Effectiveness of Instructional Methods for Their Own Learning

Data Sets Compared	Mean	Std. Deviation	t	d	r	r^2
Book/Problem-Based	3.02; 2.71	1.34; 1.16	2.644	.25	.12	.014
Book/Video	3.02; 2.45	1.34; 1.34	4.54	.43	.21	.044
Book/Collaborative	3.02; 2.63	1.34; 1.29	3.17	.3	.15	.02
Book/Direct	3.02; 2.66	1.34; 1.29	2.93	.27	.14	.02
Problem-Based/Video	2.71; 2.45	1.34; 1.34	2.07	.19	.1	.01
Problem-Based/Direct	2.71; 2.66	1.34; 1.29	.41	.04	.02	.0004
Problem-Based/Collaborative	2.71; 2.63	1.34; 1.29	.651	.06	.03	.001
Video/Direct	2.45; 2.66	1.34; 1.29	1.71	.16	.08	.006
Video/Collaborative	2.45; 2.63	1.34; 1.29	1.46	.14	.07	.005
Collaborative/Direct	2.63; 2.66	1.34; 1.29	.244	.02	.01	.0001

This is an important finding because in the high-tech, fast-paced, and increasingly digital world, students still perceive book learning as more effective than learning from a video tutorial. The availability of video tutorials and online videos in general has increased dramatically in the past 10 years (Tew, 2007), but, despite the increased availability, students in this study ranked book learning as more effective than video tutorials. Not only did students rank book learning as more effective than video tutorials but students ranked video tutorials as the least effective method of instruction.

Although students believe working alone in a book based environment for the purposes of learning a new software application is most effective, students do not appear to think working in groups is completely ineffective. The data suggests that group work (collaborative learning) is considered effective as long as they are working with a common problem (problem-based learning) in mind.

It is equally important to note that students in this study ranked the effectiveness of instructional methods for themselves in the exact same order as they reported for their classmates. Although no learning style preferences were considered in this study, the data suggests that students perceive personal and peer learning styles to be similar.

Teacher Perceptions

Teachers perceived direct instruction to be the most effective method of instruction and book learning to be the least effective method of instruction. In addition to student perceptions regarding most effective learning methods, teacher's perceptions were recorded and analyzed. Teachers were asked to rate the identified methods according to their perceived level of effectiveness in their class. Teachers used a 5-point Likert-type scale when ranking each method of instruction from 1 (*not effective*) to 5 (*very effective*).

The findings reveal that teachers believe direct instruction is superior to the other methods of instruction; not surprisingly, the teachers also reported that they most commonly use direct instruction in class (see table 5).

Table 5
Teacher Ranking of Effectiveness of Instructional Methods for Student Learning

Method of Instruction	Mean Score
Book/Written Script Tutorial Learning	2
Problem-Based Learning	2.6
Collaborative Learning	2.6
Video-Based Tutorial Learning	2.8
Direct Instruction	4.6

Converse to what students reported to be the most effective instructional style, teachers believed that book learning is the least effective method of instruction for students. The difference in mean score for direct instruction when compared with other forms of instruction (Table 6, next page) returned a *t*-test value of 5.09, 4.27, 3.53, and 2.55—suggesting a statistically significant teacher preference towards direct instruction. The effect size for each comparison was likewise significant (d = 3.22, 2.7, 2.23, 1.61).

Table 6
Statistical Analysis of Teacher Ranking of Effectiveness of Instructional Methods for Student Learning

Data Sets Compared	Mean	Std. Deviation	t	d	r	r^2
Direct/Book	4.6; 2	.55; 1	5.09	3.22	.85	.72
Direct/Problem-Based	4.6; 2.6	.55; .89	4.27	2.7	.8	.64
Direct/Collaborative	4.6; 2.6	.55; 1.14	3.53	2.23	.75	.56
Direct/Video	4.6; 2.8	.55; 1.48	2.55	1.61	.63	.4
Collaborative/Book	2.6; 2	1.14; 1	.88	.56	.27	.08
Collaborative/Video	2.6; 2.8	1.14; 1.48	.24	.15	.08	.01
Collaborative/Problem-Based	2.6; 2.6	1.14; .89	0	0	0	0
Book/Video	2; 2.8	1; 1.48	1	.63	.3	.09
Book/Problem-Based	2; 2.6	1; .89	1	.4	.2	.04
Video/Problem-Based	2.8; 2.6	1.48; .89	.26	.16	.1	.01

Student and Teacher Perceptions about Instructional Methods Used in the Classroom

A comparison was performed of student perceptions of instructional methods *used* in class and teacher perceptions of instructional methods *used* in class. Two themes were discovered: (1) students perceived book learning to be the most commonly used method of instruction used in class and direct instruction to be the least commonly used method; (2) conversely, teachers reported using direct instruction the most and book learning the least. This finding is interesting because it shows a disconnect between student and teacher perceptions. Each of these issues is discussed below.

Student Perceptions

Students perceived book/written script tutorial learning to be the most commonly used instructional method in class (Table 7, next page). Strangely, students perceived direct instruction, which provided the highest grades for students, to be the least commonly used method of instruction.

Table 7
Statistical Analysis of Student Ranking of Frequency of Use of Different Instructional Methods in Class

Data Sets Compared	Mean	Std. Deviation	*t*	*d*	*r*	r^2
Book/Problem-Based	3.078; 2.939	1.401; 1.156	1.158	.11	.054	.003
Book/Direct	3.078; 2.52	1.401; 1.315	4.395	.411	.2	.04
Book/Collaborative	3.078; 2.86	1.401; 1.33	1.71	.16	.08	.01
Book/Video	3.078; 2.73	1.401; 1.33	2.73	.254	.13	.02
Problem-Based/Direct	2.939; 2.52	1.156; 1.315	3.62	.34	.17	.03
Problem-Based/Video	2.939; 2.73	1.156; 1.33	1.79	.17	.08	.01
Problem-Based/Collaborative	2.939; 2.86	1.156; 1.33	.68	.06	.03	.001
Video/Direct	2.73; 2.52	1.33; 1.315	1.7	.16	.08	.01
Video/Collaborative	2.73; 2.86	1.33; 1.33	1.05	.1	.05	.003
Collaborative/Direct	2.86; 2.52	1.33; 1.315	2.75	.26	.13	.02

Students perceived teachers as using book learning more than any other method of instruction in class (t = 1.158, 4.39, 1.71, 2.73) and much more than direct instruction (t = 4.39). Also, students perceived their teachers as using books to teach materials far more frequently than videos or other multimedia.

Teacher Perceptions

While students reported book learning to be the most commonly used method of instruction in class and direct instruction to be the least commonly used method, teachers reported the opposite—reporting using direct instruction far more than any other method of instruction (see table 8, next page). Teachers ranked book learning, which was ranked by the students to be the most used technique, to be the least used method.

Table 8
Teacher Ranking of Frequency of Use of Different Instructional Methods in Class

Method of Instruction	Mean Score
Book/Written Script Tutorial Learning	2.4
Problem-Based Learning	2.4
Collaborative Learning	2.8
Video-Based Tutorial Learning	2.4
Direct Instruction	4.6

Instead, the teachers ranked direct instruction as being used significantly more than any other method (4.6 average rating compared with 2.8 for collaborative learning, which was ranked second). When compared with the other methods (Table 9) of instruction the variance was statistically significant in each comparison (t = 4.7, 4.7, 3.29, 2.8). When compared for an effect size, educational significance was also found in each scenario (d = .83, .83, .72, .66). The difference in student and teacher perceptions is alarming when considering that students and teachers both show strong leanings about which method of instruction is most effective.

Table 9
Statistical Analysis of Teacher Ranking of Frequency of Use of Different Instructional Methods in Class

Data Sets Compared	Mean	Std. Deviation	t	d	r	r^2
Direct/Book	4.6; 2.4	.55; .89	4.7	2.97	.83	.69
Direct/Problem-Based	4.6; 2.4	.55; .89	4.7	2.97	.83	.69
Direct/Collaborative	4.6; 2.8	.55; 1.09	3.29	2.09	.72	.52
Direct/Video	4.6; 2.4	.55; 1.67	2.8	1.77	.66	.44
Collaborative/Book	2.8; 2.4	1.09; .89	.64	.4	.2	.04
Collaborative/Video	2.8; 2.4	1.09; 1.67	.45	.28	.14	.02
Collaborative/Problem-Based	2.8; 2.4	1.09; .89	.64	.4	.2	.04
Book/Video	2.4; 2.4	.89; 1.67	0	0	0	0
Book/Problem-Based	2.4; 2.4	.89; .89	0	0	0	0
Video/Problem-Based	2.4; 2.4	1.67; .89	0	0	0	0

Effectiveness of Instructional Methods in Teaching Sketchpad

Each student produced a CD cover using the software application taught in class. Students were given approximately 60 minutes to create their CD cover and turn it in electronically (85 CD covers were graded in total). A panel of 20 graders with design background graded the student work. Graders were blind as to the method of instruction received and graded student work on a 1-5 Likert scale. A grading rubric was provided to the graders.

Student grades for each group were combined and a class average grade was obtained (Table 10). Each class average was compared and analyzed to determine how effective each method of instruction proved to be in respect to the grade given. Student perceptions of higher instructional effectiveness did not correlate with higher grades received for the assignment. In fact, the data show that students receiving direct instruction scored higher than any other method of instruction. When compared with other methods of instruction (Table 11, next page) a significant difference in variance between scores for students receiving direct instruction and those receiving other instructional methods was shown for multiple comparisons (t = 2.65, .45, 2.63, .95).

Table 10
Average Grade Received by Students—Separated by Instructional Method Used

Instructional Method Received	Average Grade
Direct Instruction	3.02
Problem-Based Learning	2.95
Book/Written Script Tutorial Learning	2.87
Video-Based Tutorial Learning	2.49
Collaborative Learning	2.43

Table 11
Statistical Analysis of Average Grade Received by Students—Separated by Instructional Method Used

Data Sets Compared	Mean	Std. Deviation	*t*	*d*	*r*	r^2
Direct/Collaborative	3; 2.43	.48; .52	2.654	1.13	.49	.232
Direct/Problem-Based	3; 2.95	.48; .32	.447	.122	.06	.002
Direct/Video	3; 2.48	.48; .70	2.63	.866	.40	.016
Direct/Book-written	3; 2.86	.48; .24	.9478	.369	.18	.032
Book/Collaborative	2.86; 2.43	.24; .53	2.41	1.05	.46	.211
Book/Problem-Based	2.86; 2.95	.24, .32	.774	.32	.16	.025
Book/Video	2.86; 2.48	.24; .70	1.71	.73	.34	.116
Video/Collaborative	2.48; 2.43	.70; .53	.195	.08	.04	.002
Video/Problem-Based	2.48; 2.95	.70; .32	2.63	.86	.40	.16
Problem-Based/Collaborative	2.95; 2.43	.32; .53	3.08	1.19	.51	.26

The combined validity of multiple tests (*t*-test, Cohen's *d*) adds weight to the assertion that direct instruction appears to be more effective than collaborative learning or video-based tutorials in helping students score higher when taught a new computer software application at the junior high level. In summary, despite teacher and student perceptions regarding effectiveness and frequency of use of different instructional methods, direct instruction proved to produce the best grades for students when taught a new computer software application.

Conclusions and Recommendations

Based on the findings from this study, several conclusions and recommendations can be generalized for application by teachers of computer software applications like Sketchpad. Three are discussed below.

Use of Book Learning at the Junior High Level

Teachers need to involve the use of book learning—especially at the junior high age level. At the junior high level, students are still in the early stages of their own intellectual development (Perry, 1970), and students want (or are used to) an authority for everything they do. Students want to have someone tell them the "right way" of doing each thing and the "right answer" for each question they encounter (Perry, 1970). A book is also another authority figure in the classroom—the book can be a source of "right answers" and "right ways" for students when the teacher is not available. Books can provide a constant stream of hints, tips, tricks, and steps for students to follow as they learn new software programs. Because students can take books home, students can use them to learn on their own time, at their own pace, and in any desired location.

Another aspect of learning that is critical to students at the junior high level is praise and positive feedback. At the junior high level, as at all age levels, there is a need for reinforcement and praise—often this praise and reinforcement comes as a confirmation that one is doing the right thing, following the steps correctly, and has achieved a short-term goal along the way. When student methods, answers, or products resemble what is outlined in the book, the student receives a small measure of "praise" as they reaffirmed that their learning corresponds with what was intended.

It may be difficult for many teachers to institute and effectively use books in their classrooms; lack of books, lack of excitement for books (by the teacher or the students), and other factors may make book learning difficult in some settings. A possible alternative to a textbook is a packet for each assignment. A packet of instructions could be copied for each student and used as a reference for students to refer to throughout instruction and the process of learning.

Understanding Student Perception of Classroom Teaching Practices

Teachers need to understand the perceptions of their students in regard to the teaching practices used in the classroom. Teachers must consciously and consistently evaluate their own teaching practices and seek to understand the perceptions of their students. An understanding of student perceptions will help inform teachers regarding their instructional effectiveness and teaching methods used (Hicks, 2010). As shown in this study, frequently teacher perceptions of instructional methods being used do not match with methods perceived by students.

Teachers should explicitly ask their students about techniques used in class to discover student perceptions and not rely solely on self-evaluation techniques for discovering effectiveness of instructional methods. Video recordings and post-teaching analysis (Wright, 2008) have been shown as effective in improving teacher cognition of methods used and improving teaching effectiveness. A simple survey, questionnaire, or even an open discussion with students could also provide such feedback for a teacher.

Improving Direct Instruction Techniques

In this study, direct instruction provided the highest average student grade for the assignment and was reported by teachers to be the most effective instructional method. Teachers also reported using direct instruction significantly more than any other method of instruction. Conversely, students perceived direct instruction to be the least used method of instruction in class. Students also ranked book learning and problem-based learning as more effective than direct instruction for their own learning and their classmates learning. Teachers must find ways to improve the perception of direct instruction in the eyes of students by improving their own direct instruction techniques.

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The Use of Executive Control Processes in Engineering Design by Engineering Students and Professional Engineers

Brophy, Klein, Portmore, and Rogers (2008) admitted that, as industries are driven by the rapid development of enabling technologies, they must become more flexible and adaptive to remain competitive. This flexibility is achieved through a workforce that can utilize newly available technologies and generate innovations of their own. They further suggested that such technological capability in the workforce can only be possible if students entering higher education are prepared differently at the K-12 level, through programs that target the development of technological literacy.

Driven by the goal to improve technological literacy, the *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2002) provide a framework for increasing students' technological literacy at all levels of the K-12 curriculum through the integration of engineering design. In reference to the design component of the *Standards for Technology Literacy*, Lewis (2005) argued that it is "the single most important content area set forth in the standards, because it is a concept that situates the subject more completely within the domain of engineering" (p. 37). Consistent with its usage in society, engineering design provides an ideal platform for engineering and technology educators to integrate mathematics, science, and technology concepts for students to solve real-world (ill-structured) problems innovatively and creatively.

Executive Control Processes

A cognitive construct that is important when solving engineering design problems is executive control process, or metacognition. Flavell (1978) and Brown (1978) define metacognition as knowledge and cognition about cognitive phenomena, or the monitoring of one's own memory, comprehension, and other cognitive processes. Kellogg (1995) refers to metacognition as cognition about cognition, or thinking about thinking. It is a central feature of human consciousness that enables one "to be aware of, monitor, and control mental processes" (p. 211).

In a synthesis of the literature on metacognition, Meijer, Veenman, and van Hout-Walters (2006) found that several studies identify some commonalities of higher order (executive control) cognition. For example, Schraw and Moshman (1995) subdivide metacognitive control processes into planning, monitoring,

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and evaluation; while Pintrich and DeGroot (1990) divide metacognition into planning, monitoring, cognitive strategies, and awareness. O'Neil and Abedi (1996) also agree with the aforementioned researchers' perception of metacognition; indicating that it includes planning, monitoring, and evaluation.

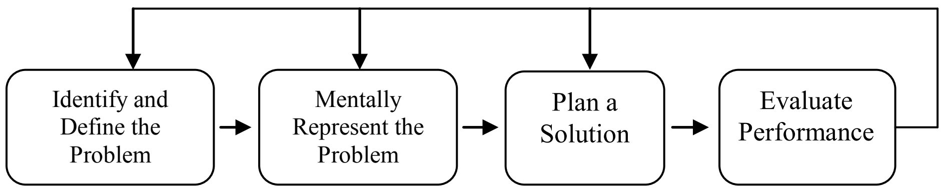
Davidson, Deuser, and Sternberg (1995) discuss four metacognitive processes that are important contributors to problem-solving performance across a wide range of domains and problem types, including well-structured and ill-structured problems (see Figure 1). When a problem is given (including a design problem), the solver must decide what is known about the problem, what design criteria are expected, and what the constraints might be. They then use representations such as metaphors, analogies, and propositions to make sense of the problem and develop a solution.

Metaphors and analogies are important representations used by designers in design problem solving (Casakin & Goldsmith, 1999; Daugherty & Mentzer, 2008; Hey, Linsey, Agogino, &Wood, 2008). Metaphorical reasoning allows one to make conceptual leaps across domains from a source to a target, such that a new situation can be characterized and understood by reference to a similar one. In respect to designing, metaphors are often used in the early stages of the design process to assist the designer in framing the problem. Besides being used descriptively to define the problem and understand the situation, metaphors can also be used prescriptively as a solution generation tool. For example, "the metaphor, Shower Is A Reset, can be used to generate solutions that could support people's feeling of starting anew even to the point of activating the shower with a button" (Hey et al., 2008, p. 288).

An analogy can be defined as the "illustration of an idea by means of another idea that is similar or parallel to it in some significant features" (Hey et al., 2008, p. 283). Analogies make possible the solution of a problem in the target domain by superimposing upon it a solution from the base domain (Lewis, 2008). In contrast to metaphors, analogies are generally used to solve functional issues and are used mainly during the generation of solutions, rather than in the framing of the design problem.

According to Paivio (1990), propositions are the most versatile of representational concepts because they can be used to describe any type of information. They are strings of symbols that correspond to natural language and which "represent information in the same way regardless of whether the information is experienced verbally, as a spoken or written sentence in whatever language, or nonverbally, as a perceptual scene" (Paivio, 1990, p. 31). The relevance of propositions for engineering design lies in the fact that they can be expressed as general principles, rules-of-thumb, or heuristics; specific physical laws, such as those used in physics; or mathematical formulas (Greca & Moreira, 1997).

Figure 1
Metacognitive processes in problem solving (Davidson et al., 1995).



According to Davidson et al. (1995), planning entails dividing the problem into sub-problems and devising the sequence for how the sub-problems should be completed. Individuals are more likely to engage in planning when solving ill-structured problems because the situation is often novel and complex, so planning or structuring brings clarity to one's intended actions. The plan is often revised or modified as the problem solver confronts obstacles during the solution process. This is consistent with Jonassen's (1997) view that ill-structured problems possess multiple solutions because they can have multiple representations and multiple problem spaces. Research shows that individuals with less expertise in solving a particular type of problem spend less time in global "up front" planning, and relatively more time in attempting a solution, than do experts across age levels and areas of expertise (Davidson et al., 1995). Studies show that designers select features of the problem space to which they choose to attend and identify areas of the solution space they choose to explore (Cross, 2006). Junior engineering students tend to gather a lot of information when solving a design task, while more experienced designers ask for less information, process data instantly, and quickly build an image of the problem.

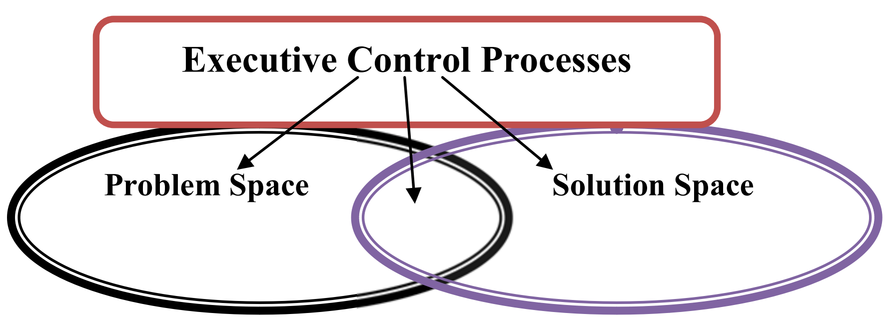
While Davidson and associates (1995) assert that monitoring as an executive control process is concomitant with evaluation, some researchers, however, treat both as separate processes (see Flavell, 1979; Kincannon et al., 1999; Schraw & Moshman, 1995; Veenman, van Hout-Wolters, & Afflerbach, 2006). For the purpose of this study, both were treated as separate processes. Schraw and Moshman (1995) define monitoring as one's awareness of comprehension and task performance, as well as the ability to engage in periodic self-testing while learning or solving a problem. The monitoring process relies on a variety of memories (such as idiosyncratic memories, emotional memories, and problem-related memories) and also on abstract rules. Although engineering design problems are ill-structured and contextually driven, the problem solver must apply abstract rules or propositions, like those used when solving well-structured problems in knowledge domains such as mathematics and physics, in order to achieve an optimal solution.

Evaluation is the appraisal of the products and regulatory processes of problem solving. According to Schraw and Moshman (1995), this typically includes re-evaluating one's goals and conclusions. The representations used by problem solvers are referenced as they appraise their performance. Davidson et al. (1995) purport that evaluation includes control over the internal representations formed, and those that still need to be formed, for understanding and solving the problem. Jonassen (1997) further adds that evaluating one's performance after the implementation of a solution includes the designer appraising: (a) whether the solution produced is acceptable to all the parties involved, (b) whether the solution is within the problem constraints articulated, (c) whether the solution is elegant or parsimonious, and (d) whether the effects of the solution could be optimized.

Conceptual Framework

The framework for this study was conceptualized by integrating the model for creative design, which illustrates the co-evolution of the problem and solution spaces during engineering design problem solving (see Dorst & Cross, 2001; Maher, Poon, & Boulanger, 1996), with executive control processes such as planning, monitoring, and evaluation. According to Maher, Poon, and Boulanger (1996), whenever engineers are solving design problems, their problem and solution spaces co-evolve with an interchange of information between the two mental spaces. Dorst and Cross (2001) confirmed the accuracy of the Maher et al. model in a protocol study of nine experienced industrial designers whose designs were evaluated on overall quality, creativity, and a variety of other aspects. For simplicity, the co-evolution of the problem and solution spaces is illustrated in Figure 2 by the overlap of the two ellipses. Superimposing elements of the Davidson et al. (1995) metacognitive model on the problem and solution spaces of Maher et al. raises questions about how designers use executive control processes throughout their problem and solution spaces.

Figure 2
Conceptual Model



Purpose of the Study

The purpose of this study was to investigate if there are differences in the cognitive process of engineering students and professional engineers as they use executive control processes (i.e., planning, monitoring, and evaluation) in the problem and solution spaces while solving an engineering design problem conceptually. The following research questions guided the study:

1. In what ways do the executive control processes (planning, monitoring, and evaluation) of engineering students and professional engineers differ in their problem and solution spaces?
2. How are propositions, analogies, and metaphors distributed throughout the use of executive control processes by engineering students and professional engineers?
3. What is the overall design strategy of the professional engineers and engineering students?

Method

A qualitative comparison of novice and expert engineers was conducted. A purposeful sampling procedure was used to select the participants. According to Gall, Gall, & Borg (2007), in purposeful sampling the goal is to select cases that are likely to be “information rich” in respect to the purpose of the study. The executive control processes of a small group of mechanical engineering students were compared with a small group of professional mechanical engineers.

Participants

An email was sent inviting juniors and seniors in a four year mechanical engineering program at a Midwestern university to particate in the study. Six mechanical engineering students agreed to participate, three junior and three senior undergraduates. The four professional engineers were recommended by a former associate dean of a college of engineering, who is also a member of the American Society of Mechanical Engineers. Each professional engineer is recognised as an expert in mechanical engineering design. Except for one professional engineer, their individual number of years in the profession exceeded the minimum 10 years of experience it generally takes to achieve expertise in a particular domain (Phye, 1986). The small sample size is typical of verbal protocal studies (Jiang & Yen, 2009; Trickett & Trafton, 2006).

The Design Task

Each participant was given the same design problem for which to find a conceptual solution. Before the design task was administered, it was vetted by two professionals in the field, an Engineering Technology professor with over 20 years teaching experience and a Mechanical Engineering professor with over 10 years experience as a manufacturing consultant and over three years experience teaching manufacturing principles. This review helped ensure that the design task was sufficiently ill-structured and of an appropriate difficulty level to engage the students and professional engineers. The final design task was then reviewed by a professor who teaches the senior design project course, and the task was pilot tested with a mechanical engineer with over 20 years experience (see Figure 3).

Figure 3
The Engineering Design Task

THE DESIGN TASK

The objective of this engineering design activity is to understand the cognitive process of engineering designers as they solve a design problem. Verbal Protocol Analysis will be used. This means that as you solve the problem you will be required to **"think aloud"** (say aloud) what you are thinking. If you stop speaking I will remind you to resume speaking aloud as you solve the problem. Please include all the notes and sketches of your solution on the sketch pads that are provided.

Duration: 1 hour

The Context

Fonthill is a hilly terrain in the District of St. Mary with narrow tracks and virtually non-existent roads. This area also experiences high amounts of rainfall yearly. There are several communities like Fonthill on this mountainous tropical island. Because of the very poor state of the roads the most frequent mode of transportation are motorcycles. Motorcycles are used to take residents to and from work, market, and school. While the residents see this system of transportation as essential, the government has serious concerns about the safety of the riders and their passengers. The government therefore secured a loan to purchase a fleet of motorcycles that are specially built to handle these rugged terrains. These motorcycles will be leased as taxis to specially trained riders.

The Design Problem

The Honda CRF230 shown on the next page is a cross between a dirt bike and a street bike. Modify the Honda CRF230 so that it is robust enough to handle repeated journeys through these mountainous terrains that are prone to a lot of rainfall annually. The average cost of a new car in this country is about US$25000.00 and the government expects that the cost of this motorcycle will not exceed one-third this cost. The motorcycle must also:

- Be equipped with more cargo carrying capacity and at the same time make the rear seating (pillion) more comfortable.
- Have an improved rack or a holding system for carrying packages, books, or a reasonable amount of groceries on the motorcycle. The rack must be non-metallic but of sufficient sturdiness to withstand a rugged terrain, occasional brushing against rocks, and a lot of rainfall.
- Be capable of enough horsepower to climb sections of mountains with slopes of 30 degrees, carrying the rider and the pillion passenger.
- Have a device to prevent the theft of helmets from the motorcycle.

Procedure

The design task was administered at a time and place convenient for each participant. Pencils, erasers, and sketchpads were provided, along with the instructions for the design task. Each participant was allowed approximately one hour to complete the design solution. A $25 gift card was given to each participant. Participants were required to produce only one conceptual design.

Data were collected primarily through Verbal Protocol Analysis. The first stage of data collection, referred to as concurrent protocol, was carried out while the design problem was being solved. The second stage of data collection, referred to as retrospective protocol, was performed immediately after the problem was solved.

Each participant had the choice of doing a verbalization practice session of about five minutes, thinking aloud as they solved a simple mathematical problem, to prepare them for the study. After they were comfortable with the thinking aloud process, the task was administered. The participants were encouraged to speak aloud whatever they were thinking as they solved the problem. Their think-aloud verbalizations were audio recorded. If the participants stopped talking, they were prompted or reminded to continue to speak aloud what they were thinking.

After each participant completed the engineering design problem, an interview was conducted to clarify sections of the protocol and to allow the participant to explain the executive control processes that were applied. Like the concurrent protocol, the interviews were audio recorded. Their response to the reflective interview questions served as a supplementary data source to the concurrent protocols. A general interview guide format was used. According to Gall et al. (2007), with the general interview format, no set of standardized questions is written in advance because the order in which the topics are explored and the wordings of the questions are not predetermined.

Data Analysis

The audio recordings of the concurrent and retrospective protocols were transcribed. The transcribed protocols were then segmented into think-aloud utterances, divided into sentences, and coded. The quality of the sketches was not evaluated since the objective of the study was to examine the mental processes of the engineering students and the professional engineers while they solved the design task. The sketches and notes, however, acted as a reference to clarify some sections in the protocols.

The purpose of segmenting is to break the transcribed verbal protocol text into units (or segments) that represent discrete thoughts and can be coded with a pre-defined coding scheme. Codes were provided for nine predefined constructs identified from the literature reviewed on metacognition, analogies, problem solving, and design (e.g., Casakin & Goldschmidt, 1999; Cross, 2006; Schraw & Moshman 1995; Hey et al., 2008). The codes were consistent with the constructs described in the model for metacognitive processes in problem solving (Davidson et al., 1995) and the model for creative problem solving (Dorst & Cross, 2001; Maher et al., 1996).

The constructs representing the participants' mental representation were proposition, analogy, and metaphor. Those representing the participants' executive control processes were planning, monitoring, and evaluation. The mental spaces describing the problem-solving episode were problem space, solution space, and overlapping space (see Table 1, next page). There were a total of 270 utterance segments (150 for the professional engineers and 120 for the engineering students).

Reliability coding was conducted by having two persons code seven pages of one transcript (Miles & Huberman, 1994). A reliability kappa coefficient of 0.76 was calculated for the first coding. All disagreements between coders were resolved through discussion. A second coding was done by both coders on the same number of pages of another transcript and a reliability kappa coefficient of 0.9 was calculated. One coder then completed the coding of the remaining transcripts.

Table 1
Constructs, Codes, and their Meaning

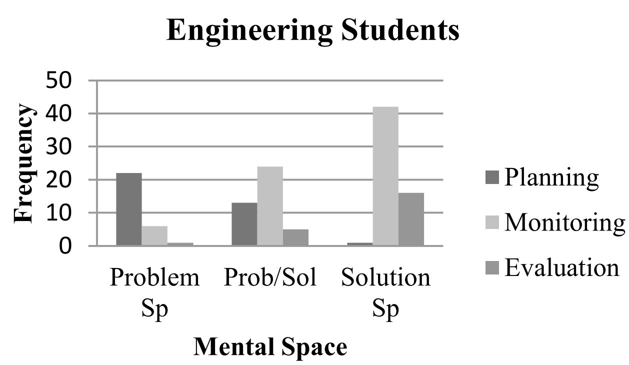
Construct	Code	Meaning
Propositions	Prp	Mathematical and engineering science formula and rule-of-thumb or heuristics used for example in analysis—e.g., *$F= mv^2/r$; "lowering the frame will lower the center of mass."*
Analogies	Anl	Comparing an idea with another idea that is similar in structural and relational features—e.g., *comparing the surface texture of a leaf with the surface texture of a plate in a battery; Comparing two types of motorbikes*
Metaphors	Mta	Allows one to make conceptual leaps across domains from a source to a target so that a new situation can be characterized and understood by reference to a familiar one. They help to provide meaning to a design situation—e.g., *viewing a gas station design problem as an oasis. Understanding a design situation by comparing an electronic book delivery design to a restaurant metaphor (Hey et al., 2008).*
Planning	Pla	Dividing the problem into sub-problems and strategizing how to reach a solution—e.g., *Gathering data, prioritizing the requirements in design brief, identifying constraints.*
Monitoring	Mon	Engaging in periodic self-testing and assessment of the quality of design as one progress to a solution—e.g., *Performing analysis; testing the accuracy of a formula, calculation, or sketch for the accuracy of a clamping force.*
Evaluation	Eva	Appraising or judging whether the solution of a design meets constraints, costs, and all the demands of the stakeholder; judging quality of two or more design—e.g., *Appraising whether one component is designed with the cheapest material that can guarantee the required strength and quality required by the customers.*
Problem space	Prb-sp	Includes design activities such as gathering information, defining the problem, identifying constraints, specifying evaluation criteria, and initially searching alternative solutions.
Solution space	Sol-sp	Includes activities such as developing a solution, sketching, drawing, deciding between two alternatives, optimizing a selected solution, and determining specifications.
Overlapping spaces	Prb-Sol	The mental space where information is interchange between problem and solution spaces. Involves consulting the design brief to make verification then returning to the solution or start a new solution. Activities include analysis and the selection of alternative solutions.

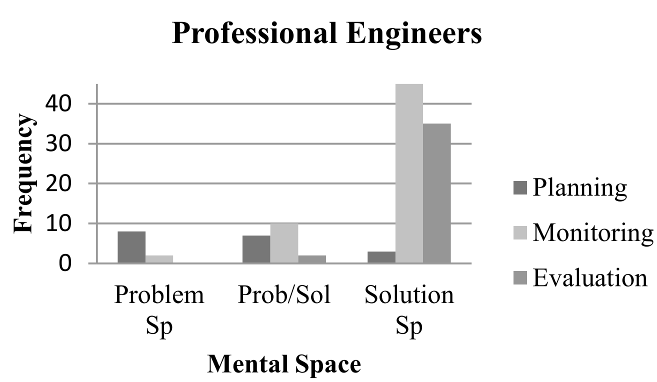
Results

Executive Control Process Frequency and Characteristics

As illustrated in Figure 4, the frequency of planning activities for both groups decreased, while the frequency of the monitoring and evaluation activities for both groups increased, as they progressed from the problem space to the solution space. The frequency of the professional engineers' executive control processes was higher in the solution space (83) than the engineering students (59). Overall, the engineering students had a higher frequency of planning activities than the professional engineers.

Figure 4
Frequency Histograms Comparing Engineering Students and Professional Engineer Executive Processes





The engineering students showed major increases in the frequency of their monitoring activities in the problem space (6) and solution space (42). The professional engineers also showed major increases in their monitoring activity from the problem space (2) to the solution space (45); however, the engineering students displayed more monitoring activities in the overlapping space (24) than the professional engineers (10). The professional engineers did not show any signs of evaluation in the problem space and showed very little in the overlapping space (2), but the frequency of evaluation in the solution space increased significantly (35). The professional engineers used more executive control activities on average than the engineering students.

Table 2
Characteristics of Executive Control Processes

Metacognitive Regulation	Characteristics	
	Engineering Students	**Professional Engineers**
Planning	Spent more time planning. Used analogies to help in the framing and understanding the problem. *"So what I am doing right now is trying to think of other road vehicles, their seating like for example four wheelers, their seating and the racks are much wider, so we could possibly make the rear a little wider by extending the frame…"*	Spent less time planning Planning strategies more driven by engineering science principles rather than analogical features. *"So I lowered the center of gravity of the load and extended the wheel-base for stability. Okay I have an initial concept for moving forward."*
Monitoring	The majority of metal representations were exhibited during monitoring, and analogies were used more frequently than propositions. Safety seems to be the main factor that drives the assessment and optimization of the quality of a solution. *"The exhaust I think might cause a problem with the rider. I think the more shielding would have to be implemented to prevent the rider or any cargo from burning."*	The majority of metal representations were exhibited during monitoring, and analogies were used more frequently than propositions. Most of the monitoring activities focus at improving the customer safety and comfort. "*But this I mean to make the passenger more comfortable we've got to do a better job of seating*"
Evaluation	Spent less time on evaluation	Spent more time on evaluation

Table 2 illustrates the main characteristics of the engineering students' and professional engineers' executive control processes. These characteristics were identified by themes that were common in the protocols for all four of the engineering students and three of the professional engineers.

Mental Representations and Design Strategy

The engineering students and the professional engineers used different amounts of propositions, metaphors, and analogies in their planning, monitoring, and evaluation. Only three of the engineering students (Don, Gus, and Len) and one professional engineer (Mac) used metaphors while they were planning. One engineering student (Len) and one professional engineer (Mac) used a metaphor while carrying out monitoring activities.

The engineering students used only analogies in their evaluation, except for one (Hank) who used both analogies and propositions. In contrast, two of the four professional engineers used both analogies and propositions in their evaluation; one used only analogies, and one did not use any mental representation. Overall, most of the mental representations that were used by the engineering students and professional engineers occurred while they were monitoring their design solution. One engineering student (Hank) deviated from this pattern, using most of his mental representation during evaluation. The second highest number of mental representations was used during the planning of the engineering students and during the evaluation of the professional engineers.

There were several differences and similarities in the engineering design strategy used by the engineering students and professional engineers. The professional engineers, on average, took a longer time to solve the design task than the engineering students (professional engineers 47.17 minutes; engineering students 30.17 minutes). The protocols revealed that some students and professional engineers showed a determination not to deviate from an early concept. This behavior is similar to findings indicating that experienced mechanical engineering designers and senior design students tend to attach to early solution ideas and concept (Ball, Evans, & Dennis, 1994; Ullman, Dietterich, & Stauffer, 1988). For example, the student Len, stuck with an ATV design idea from the beginning to the end of his design.

> LEN: **(After about 2 minutes into his solution)** *...and if you like a back seat like an ATV type it would be considerable more comfortable than having two people on one motorcycle.* **(About 25 minutes later)***...okay for safety my original design is definitely safer because it's two people sitting in an enclosed area and the bars here would be metal so they at more of a roll bar like on ATVs.*

The professional engineer Kirk showed a similar attachment to a concept that he had from the beginning of his solution.

> KIRK: **(After about 3 minute into his solution)** *...my initial thought was some sort of an articulated vehicle that would be attached to the rear of the motorcycle that would carry the passenger and/or luggage and provide stability.* **(About 32 minutes later)***...my original concept for two rear wheels revolves around a rickshaw type concept where you would still essentially have four tires for the total vehicle. The rickshaw would provide a stable ride for the passenger to get out carry lots of load; it would be a really nice solution.*

The general design recommendation from both groups was a motorbike with a carriage compartment at the back; flatter, lower seats with a backrest; and broad wheels and locks to secure the helmets. There was remarkable similarity, and not much variance, in the alternative solutions of both the engineering students and the professional engineers. For example, both groups considered using a saddlebag in the center of the bike, a four wheel ATV type vehicle, a three wheel ATV type vehicle, a bike with a passenger carriage to the side, and a bike with a luggage carriage that is pulled from the back.

Discussion and Conclusions

The small purposeful sample used does not allow for generalized statements to be made about the mechanical engineering design process of professional engineers and engineering students. The findings from this qualitative study, however, confirm previous findings of other studies and provide useful insights about the executive control processes of student and professional mechanical engineer designers.

Three conclusions were drawn from the findings. The first is that expert planning and monitoring is driven by propositions, while the novice planning and monitoring is influenced by analogical comparisons. One possible reason the students used more analogical comparisons in their planning and monitoring is because they were not familiar with the type of design problem, and so they drew upon similar types of design to aid them in defining the problem and finding solutions. In contrast, the professional engineers, because of their years of experience, could easily understand the nature of the problem and, therefore, relied more on engineering science formulas and heuristics in their planning and monitoring.

The second conclusion is that mental representations are used mostly when the engineering student and professional engineers are monitoring their design solutions, and the professional engineers are more balanced than the students in their use of analogies and propositions. This conclusion is reflective of one of the themes identified by Jonassen, Strobel, and Beng Lee (2006) in a qualitative study of engineers in their natural working environment. They found that instead of relying on one form of representation, engineers use multiple forms of problem representation in their day-to-day practice.

The third conclusion is that evaluation plays a larger role in the solution space of professional engineers, while engineering students do more planning in the problem space. The decrease in planning activities and increase in monitoring and evaluation activities, as the designers move from the problem space to the solution space, were consistent with what Davidson et al. (1995) implied about metacognition in problem solving. The findings, however, indicate that the engineering students did more planning than the professional engineers. This conflicts with literature on metacognition in problem solving. For example, Davidson et al. (1995) stated that "individuals with less expertise in solving a particular problem seem to spend relatively less time in global 'up front' planning for solution, and relatively more time in attempting to implement a solution than do experts" (p. 218). Atman et al. (2007) also found that expert mechanical engineers spent twice as much time in problem scoping activities, such as problem definition and gathering information, which are elements of planning. The professional engineers in this study may not have needed to spend much time for planning due to their past experience, as planning may be so familiar to them that they simply move into articulating their thoughts about solutions.

It is not surprising that the professional engineers used more monitoring and evaluation in the solution space. In fact, the literature on metacognition indicates that experts excel in these self-regulatory and appraisal skills. Experienced engineers were observed to make preliminary evaluations of their tentative decision, perform final evaluation, balance systems of benefits and tradeoffs, and use guidelines and rules-of-thumb when making decisions (Ahmed, Wallace, & Blessing, 2003; Crismond, 2007). The time spent in decision making is likely to be related to the time spent generating and evaluating solutions (Radcliffe & Lee, 1989).

Implications

The fact that the professional engineers used multiple forms of representations strengthens the suggestion of Jonassen and associates (2006) that design curriculum and pedagogy should not rely exclusively on algebra, calculus, and trigonometric formulas to represent problems, but students should be taught how to supplement these propositional representations with other alternative qualitative problem representations.

The *Standards for Technological Literacy: Content for the Study of Technology* state, "as a part of learning how to apply design process students in grade 9-12 should… evaluate the design solution using conceptual, physical, and mathematical models at various interval of the design process in order to check for proper design and note areas where improvement is needed" (ITEA, 2002, p. 123). Evaluation is recognized as a higher order cognitive skill at which experts excel. Therefore, design curriculum and teaching strategies should target the development of these skills. Engineering and technology students should be taught how to use both quantitative and qualitative analytical methods to frame their strategy and monitor their design conceptualizations. In later stages of the design process, students can be taught how to determine the best alternative solutions by the conducting of scientific tests. This will also improve their evaluative skills. According to Crismond (2007), "Students can develop their own guidelines based on tests they conduct by formulating design rules-of-thumb. Design rules-of-thumb can strengthen the link between science and engineering design and amount to intermediate abstractions that link the concrete realities of a particular mechanism and product with relevant concepts and laws from engineering and the natural sciences" (p. 27).

The increased evaluation activities by the professional engineers were evident primarily when they reflected on or reviewed their processes and solutions. Self-monitoring and evaluation are associated with higher levels of design quality (Crismond, 2007). Therefore, strategies used in grades 9-12 ETE classrooms should allow students to reflect on and critique their own and other's design process and product. Crismond recommends that giving students practice at identifying others' design strategies can make their design-oriented metacognition more accurate and automatic.

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2. All manuscripts must be double-spaced and must adhere to the guidelines published in *Publication Guidelines of the American Psychological Association* (6th Edition). **Tables and figures, however, should be imbedded within the text itself rather than at the end of the document.**
3. **All figures and artwork must be scalable to fit within the JTE page size (4.5" x 7.25" column width and length) and included electronically within the document.**
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