Contents

From the Editor

Jackie Robinson, Molybdenum, and the *JTE*

Jackie Robinson played baseball for the Brooklyn Dodgers and wore number 42. Molybdenum (Mo), an element that is used in the making of high-strength steel alloys, has the atomic number 42. The *Journal of Technology Education* (*JTE*), formerly under the guidance, leadership, and editorial responsibilities of Drs. Mark Sanders and James LaPorte has been published internationally in 21 volumes, (42 issues). Forty-two is more than the next number after 41!

My name is Chris Merrill and I am Professor and Coordinator of the Technology Education Program at Illinois State University. It is my pleasure to welcome you to the Fall 2010 edition of the *JTE*. Although I would have liked to have published my first edition earlier and on time, I hope that you will understand since my transition into the position occurred very late in the summer. On behalf of the profession, I want to extend a sincere debt of gratitude to Drs. Mark Sanders and James LaPorte for all of their dedication to and exemplary work on behalf of the *JTE;* it is truly my honor to follow the efforts of these two scholars as I move into the editorial position of the *JTE*.

Before I highlight the authors and their manuscripts in this issue, I want to uncover an editorial that appeared in the *JTE* some time ago that still has significant meaning to me as a scholar, educator, and editor. One of the fondest and profound writings in the *JTE*, at least for me personally, was written in 1994 (Must we MST?) by Patrick Foster, then a doctoral student at the University of Missouri-Columbia. At the time of Foster's editorial, I was teaching high school technology education and beginning to slowly infuse mathematical concepts into my curriculum. Foster's writing helped solidify my position as a technology education teacher and greatly influenced my decision to study integrated mathematics, science, and technology at the doctoral level.

Foster's questions posed in 1994 regarding mathematics, science, and technology remain pertinent today in regard to the addition, infusion, integration of engineering into technology education. In his editorial, Foster posed eight questions to the field. For purposes of this editorial, I would like to restate four of his original questions. The first question was "Is MST being strongly advocated by the profession?" His second question was "What are the benefits of MST?" A third question that guided his editorial was "Are math and science leaders conscious of technology education?" A fourth question was stated, "Will public school math/science integration ever happen?" With the emphasis in our field strongly shifting toward engineering, can we replace Foster's "MST" with engineering? Can MST be replaced by science, technology, engineering, and mathematics (STEM)? What is the "Must We" for technology education in the decade(s) ahead? Foster stated, "Admittedly, asking questions is easier than answering them. However, it is probably much better to question while answers are difficult than to reserve questioning until answers are futile" (p. 76).

In this edition of the *JTE*, you will find a multitude of scholarly articles with research-based findings. For example, Custer, Daugherty, and Meyer contributed an article that synthesizes an extensive literature review surrounding the formulation and concept base for engineering at the secondary level. Mentzer and Becker have prepared an article based on academic preparedness as a predictor of achievement in engineering design. Rose has provided the readership of the *JTE* with an article based on enhancing environmental literacy and technology assessment skills. Burghardt, Hecht, Russo, Lauckhardt, and Hacker have written a piece on the infusion of mathematics in middle school technology education classes. Foster has provided the field with an article on graduate research in technology and engineering education centered on the years 2000-2009. Finally, Bowen, a graduate student and kindergarten teacher, has provided a book review on *Using Technology with Classroom Instruction that Works*. Needless to say, there is a wealth of information in this edition of the *JTE*, so I hope you enjoy reading it as much as I enjoyed the editorial process.

For each of you that have been loyal subscribers and followers of the *Journal of Technology Education*, I would tend to think that you could identify one or two manuscripts that have significantly influenced your professional approach toward technology education. For newcomers to the *JTE*, I truly hope that you find "that manuscript" which helps shape your thinking and approach. I look forward to serving the technology and engineering educator's profession for many years to come, especially during (you guessed it) my 42nd birthday, as Editor of the *Journal of Technology Education*.

Chris Merrill

Foster, P. (1994). Must we MST? *Journal of Technology Education*, 6(1), 76-84.

Articles

Formulating a Concept Base for Secondary Level Engineering: A Review and Synthesis

Rodney L. Custer, Jenny L. Daugherty, and Joseph P. Meyer

Introduction

In recent years, there has been growing interest in science, technology, engineering, and mathematics (STEM) education across the K-12 spectrum (e.g., Borgman, Abelson, Dirks, Johnson, Koedinger, Linn, Lynch, Oblinger, Pea, Salen, Smith, & Szalay, 2008; National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Mathematics Advisory Panel, 2008; National Research Council, 2006). In part, this interest has been triggered by a "growing concern that the United States is not preparing a sufficient number of students, teachers, and practitioners in the areas of science, technology, engineering, and mathematics" (Kuenzi, 2008). While much of the focus on STEM has concentrated on science and mathematics, engineering and technology are emerging as disciplines in their own right at the K-12 level (Coppola & Malyn-Smith, 2006). A significant part of this emphasis on engineering and technology can be attributed to a concern that insufficient numbers of students are being attracted into and prepared for post-secondary engineering education (Brophy, Klein, Portsmore, & Rogers, 2008). There is also a growing awareness that an engineering presence within the K-12 curriculum provides an authentic contextual base for mathematics and science concepts (Daugherty, Reese, & Merrill, in press; Lewis, 2005; Wicklein, 2006).

One large scale initiative focused on pre-college engineering is the National Center for Engineering and Technology Education (NCETE) funded through the National Science Foundations' (NSF) Centers for Learning and Teaching program (Hailey, Erekson, Becker, & Thomas, 2005). One key problem that emerged from a multiple case study project of engineering teacher professional development funded by NCETE was the lack of a well-defined conceptual base for K-12 engineering (Daugherty, 2009). The development of meaningful learning, teaching, and assessment is problematic in the absence of a clear understanding of the conceptual base of the subject matter—in this case K-12 engineering (Bransford, Brown, & Cocking, 2000). Given the current ambiguity

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of the conceptual base of secondary engineering, and the need for conceptual clarity in curricula, professional development, and research, this study was designed to coalesce a body of engineering concepts for the secondary level.

Purpose of the Study

The purpose of the study was to identify and refine a conceptual base for secondary level engineering education. Specifically, this study addressed the following research questions:

1. What engineering concepts are present in the pertinent literature including: philosophy of engineering; secondary level science, technology, engineering, and mathematics standards; secondary level engineering-oriented curriculum; and the related research literature?
2. What engineering concepts are deemed core for secondary level education by practicing engineers and engineering educators?

Literature Review

Many have targeted the engineering design process as the avenue for integration (Lewis, 2005; Wicklein, 2006). The implementation of engineering design into technology education has largely centered on process through a step-by-step approach (Hill & Anning, 2001). This approach however has been increasingly criticized because it contradicts both expert and novice designers' approaches to the problem solving and design process (Lewis, Petrina, & Hill, 1998; Mawson, 2003; Welch, 1999; Williams, 2000). In addition, a focus on process may not lead to conceptual learning (Eisenhart, Borko, Underhill, Brown, Jones, & Agard, 1993; Rittle-Johnson, & Alibali, 1999; Rittle-Johnson, Siegler, & Alibali, 2001). As Antony (1996) argued, teachers "may be lulled into a false sense of security by providing students with numerous investigations, open-ended problem-solving experiences, and hands on activities with the expectations that students are successfully constructing knowledge from these experiences" (p. 351).

The lack of a defined conceptual base is a concern. As Erickson (2002) argued, attempting to "teach in the 21st century without a conceptual schema for knowledge is like trying to build a house without a blueprint" (p. 7). Conceptual knowledge is essential for learning as it requires understanding the operational structure of something and how it relates to associated concepts. Conceptual knowledge can be "thought of as a connected web of knowledge, a network in which the linking relationships are as prominent as the discrete pieces of information" (Hiebert & Lefevre, 1986, p. 3-4). Concepts are organizing ideas that are timeless, universal, abstract and broad, represented by one or two words, and examples of which share common attributes (Erickson, 2002; Tennyson & Cocchiarella, 1986).

There have been several studies, largely utilizing a modified Delphi and/or survey approach, in the past few years that have sought to identify K-12 engineering outcomes (Childress & Rhodes, 2008; Childress & Sanders, 2007; Dearing & Daugherty, 2004; Hacker, de Vries, & Rossouw, 2009; Harris &

Rogers, 2008). As Katehi, Pearson, and Feder (2009) pointed out, there are common concepts that appear on most of these lists including systems, modeling (representational and mathematical), predictive analysis, specifications, constraints, optimization, and trade-offs. However, these studies focused on something other than articulating the concept base for engineering at the secondary level (i.e., engineering outcomes, dispositions, skills) through a process of consensus. This study aims to identify the conceptual base particular to engineering education at the secondary level by consulting multiple sources including philosophy, curriculum, standards, and experts.

Method

Operating under an emergent qualitative research design, an adaptive approach to data collection was utilized (Schwandt, 2001). This type of emergent strategy is characteristic of situations where researchers are attempting to extract and interpret meanings from within a larger context and where strategies are needed to retain an emergent quality (Patton, 1990). In addition, multiple methods were utilized to achieve triangulation and "secure an in-depth understanding of the phenomenon in question" (Denzin &, Lincoln, 2005, p. 5) (i.e., engineering concepts). The initial data collection plan included a review of secondary level engineering curriculum materials and STEM curriculum standards, as well as focus groups of engineering education experts. After a review of the conceptual learning literature and consistent with emergent qualitative designs, the research team realized that a more in-depth understanding of conceptual literature was necessary. To address this concern, an in-depth review of the engineering and technology philosophy literature was added to the methodology in order to help fully define the domain. The decision to include literature from both engineering and technology was made due to the substantial conceptual overlap in the philosophical and historical literature. For example, a review of work published in a variety of sources including *Technology and Culture* (Society for the History of Technology) and Techné (Society for Philosophy and Technology) includes substantial treatment of both technology and engineering, both for illustrative and analytical purposes.

Ultimately, four sets of documents were reviewed and three focus groups were conducted. The documents, in the order they were reviewed, included: (a) engineering and technology philosophy writings, (b) curriculum materials focused on secondary level engineering, (c) curriculum standards documents developed for the STEM disciplines and National Academy of Engineering reports, and (d) survey research studies relevant to K-12 engineering. Following the compilation and analysis of the focus group and document review data, a peer debriefing (Schwandt, 2001) with engineering and technology education experts was convened to review and discuss the study's methods and outcomes.

Extant Document Review

The goal of the document review was to systematically identify and review key documents to identify core engineering concepts (see Table 1). The selection of documents for analysis varied depending on type. The philosophy documents were selected based on the work of one of the researchers whose doctoral dissertation included a thorough treatment of engineering and technology philosophy literature. That study included a systematic document selection process, which included nominations, discussion, and, ultimately, a vote by a national panel of experts (Custer, 1991, 1995).

Table 1
Document Types and References Reviewed for Study

Document Type	References
Philosophy Writings	*Engineering Philosophy* (Bucciarelli, 2003) *Thinking Through Technology: The Path Between Engineering and Philosophy* (Mitcham, 1999) *The Introspective Engineer* (Florman, 1996) *Engineering as Productive Activity* (Mitcham, 1991) *The Social Captivity of Engineering* (Goldman, 1991) *The Eco-philosophy Approach to Technological Research* (Skolimowski, 1991) *Deficiencies in Engineering Education* (Ropohl, 1991) *What Engineers Know and How They Know It* (Vincenti, 1990) *Ethics and Engineering* (Martin & Schinzinger, 1996) *Definition of the Engineering Method* (Koen, 2003) *Autonomous Technology and Do Artifacts Have Politics* (Winner, 1977) *Technology as Knowledge* (Layton, 1974)
Curricula	*A World in Motion* *Design and Discovery* *Materials World, Engineering by Design* *Engineering the Future* *Exploring Design and Engineering* *Ford Partnership for Advanced Students* *INSPIRES* *Project Lead the Way* *The Infinity Project*
Curriculum Standards & Related Documents	*Benchmarks for Science Literacy* (AAAS, 1993/2009) *Criteria for Accrediting Engineering Programs* (ABET, 2000) *National Science Education Standards* (NRC, 1996) *Principles and Standards for School Mathematics* (NCTM, 2000) *Standards for Technological Literacy* (ITEA, 2000) *The Engineer of 2020* (NAE, 2005)
Research Studies	Childress and Rhodes (2008), Harris and Rogers (2008), Childress and Sanders (2007), Smith (2006), Dearing and Daugherty (2004)

Curriculum materials were drawn from those identified in the K-12 engineering study conducted by the National Academy of Engineering (Katehi, Pearson, & Feder, 2009). For the purposes of this study, with guidance from the NAE project curriculum analysis consultant (Dr. Kenneth Welty), only those units within the high school curricula that were directly related to engineering were reviewed. The standards documents included in the study were those developed by the professional organizations representing the STEM disciplines. The research studies were identified through electronic database searches based on their relevance to secondary level engineering.

A standard process was developed and used to review each set of documents. Two of the three researchers, alternating the pair of researchers, independently reviewed each set of documents and identified "engineering themes" in the narrative. To ensure adequate coverage, each document was reviewed by two of the three researchers. Engineering themes were those elements in the narrative that were described as important to engineering and applicable across various engineering disciplines, as informed by the philosophy of engineering and technology literature. At this stage, the decision was made to be inclusive, retaining themes that would later be analyzed and refined through a systematic, analytical procedure employed by the research team.

Criteria were used to evaluate each theme according to an agreed upon understanding of how it met definitions of core, engineering, and concept. From the list of engineering themes, all three researchers independently identified what they considered to be core engineering concepts using the following specified definitional criteria:

- Engineering: defined by the Accreditation Board for Engineering and Technology (ABET) as the knowledge of the mathematical and natural sciences—gained by study, experience, and practice—, is applied with judgment to develop ways to use, economically, the materials and forces for the benefit of mankind (Gomez, Oakes, & Leone, 2006).
- Concepts: Abstract labels (Erickson, 2002), organizing ideas (Hiebert & Lefevre, 1986), typically represented with one or two words (Sigel, 1983), and take on meaning in the knowledge-rich contexts in which they are applied (Tennyson & Cocchiarella, 1986).
- Core: The center of an object, a small group of indispensable things, and the most essential or most vital part of some idea or experience (Wordnet, 2009).

The research team applied the criteria to all of the themes that emerged from the analysis. The criteria were applied individually in the order presented above. If a theme "failed" to meet any of the criteria, it was eliminated from consideration. In order to be included in the listing of core engineering concepts, the theme was required to meet all three criteria by all three researchers on a consensus basis.

With the "engineering" criterion, the focus was on whether the theme focused specifically on the study, expertise, and practice specific to engineering. With the "concepts" criterion, the team's deliberations concentrated on the perceived robustness and complexity of the ideas and the extent to which they could be "unpacked," as well as the extent to which they extended well beyond processes and procedures. The "core" criterion focused on the extent to which the ideas were perceived to be essential to engineering as well as their appropriateness to secondary level education.

To the extent possible, the review identified concepts distinct from the more procedural aspects and interpersonal dispositions of engineering. Procedural items consist of those where the primary emphasis is on the more technical aspects of accomplishing an engineering design. For example, a set of heuristics or technical stages or steps used to optimize a particular design was excluded from the study due to its lack of conceptual robustness. Similarly, while social/interpersonal dispositions such as communication skills, teamwork, and time management skills are central to engineering, they focus more on the attributes needed to succeed in engineering rather than on the discipline's core ideas.

Focus Groups

In addition to the thorough document review, the researchers conducted three focus group sessions with a total of 21 engineering educators and practicing engineers from selected departments of engineering and local engineering firms. These individuals had a recognized interest in and expertise with the broader, conceptual aspects of engineering. One focus group session was conducted at Colorado State University and two at Virginia Tech University. A point person at each of the universities, both of which are actively engaged in secondary level engineering education, identified participants based on guidance from the researchers. The point persons had been engaged in research and professional activities associated with engineering education and were well-equipped to select participants based on the study's selection criteria.

The purpose of these sessions was to capture participants' thinking about engineering concepts. The sessions were facilitated using an affinity group process. Participants were provided with an overview of the three criteria used to define core engineering concepts and then asked to brainstorm and record concepts onto sticky notes. As a group, the participants then clustered the concepts into categories and named each of the categories on a consensus basis. They were then asked to classify the categories into three columns: (a) those core to engineering, (b) those very much on the fringe, and (c) those undecided or somewhere between core to and on the fringe of engineering. Finally, the participants were asked to conduct one final review of their lists against the three selection criteria that were used for the study. This process generated a set of core engineering concepts from the perspective of practicing engineers and engineering educators.

Peer Debriefing

The culminating activity of the study consisted of a peer debriefing conducted by a panel of six engineering and technology education experts for a half-day discussion. The purposes of the activity were (a) to review the process used to conduct the study and (b) to discuss the findings. Peer debriefings allow qualitative researchers the opportunity to confide in “trusted and knowledgeable colleagues and uses them as a sounding board for one or more purposes” (Schwandt, 2001, p. 188). For the purposes of this study, colleagues were selected based on the researchers’ views of their recognized ability to think conceptually, knowledge of secondary level education, and understanding of engineering education.

Findings

The synthesis of the 5 major analyses yielded over 100 themes judged by the research team to be pertinent to engineering. The themes consisted of ideas, terms, and constructs that were judged by the researchers to be important to engineering. As noted earlier, the approach during this phase of the analysis was to be broad and inclusive. The next step of the refinement process consisted of subjecting the set of themes to the three criteria that were established for the process—that the themes were “core," “engineering,” and “conceptual." Each member of the research team independently applied the three criteria central to the analysis to each of the themes. Subsequent to these individual analyses, the team engaged in extensive discussions to achieve consensus until a composite listing of concepts, across all five inputs, was compiled. In those cases where consensus was not achieved, the item was not included in the listing of core engineering concepts.

Table 2 depicts the set of thirteen concepts that were generated through this process. In addition to the list of concepts, column two contains a set of descriptive terms associated with each concept. These terms were drawn directly from the document sources and were used to define, clarify, or illustrate the concepts. The remaining columns provide an indication of where the concept was located within the five sources of input. Careful records were maintained to track the sources of themes and concepts derived from all five sources throughout the analysis, which provided the documentation needed for the information presented in the “sources of input” columns in Table 2.

Table 2

Core Engineering Concepts and Presence in Data Sources

		Sources of Input				
Concept	Terms	Curriculum	Philosophy	Standards	Focus Groups	Survey Studies
analysis	risk, cost/benefit, life-cycle, failure, mathematical, decision, economic	P	P	P	P	P
constraints	criteria, specifications, limitations, requirements	P	P	P	P	P
design	iterative, technological, analysis based, experimental, ergonomic, universal	P	P	P	P	P
efficiency	key engineering goal, guiding principle	P	P	P	NP	NP
experimentation	testing, test development, trial and error	P	P	P	P	P
functionality	key engineering goal, usefulness, practicality	P	P	NP	P	P
innovation	creativity, improvement, refinement, invention	P	P	P	P	P
modeling	mathematical, computer-based, technical drawing, physical	P	P	P	P	P
optimization	improvement, refinement, balancing, decision heuristics	P	P	P	P	P
prototyping	physical and process modeling and evaluation, preliminary	P	P	P	P	P
systems	input/output, process, feedback, component design and interaction, subsystems	P	P	P	P	P
trade-offs	conflicting constraints, negotiation, competing requirements or criteria	P	P	P	P	P
visualization	imagery, spatial and abstract representation, sketching	P	P	P	NP	P

Note. P indicates concept present in data source, NP indicates concept absent from data source

The listing of concepts presented in column one of Table 2 represents a distillation of over 100 themes. A substantial number of themes were deemed to have met the "core" and "engineering" criteria, but not the "conceptual" criterion. While these are important ideas, the goal of this study was to carefully identify ideas judged to be conceptually robust. Examples of items classified as non-conceptual included technical research, refinement, testing, and reverse engineering. Of those that met all three criteria, remarkable conceptual consistency was observed across the study's five major inputs. Ten of the thirteen concepts were represented in all five inputs and two additional concepts were represented in four of the inputs. It is also clear that considerable conceptual overlap exists among the concepts. For example, many of the concepts represent aspects of the engineering design process.

A brief comment should also be made about the items presented in the "Terms" column. Prior to applying the three criteria, the approach was to be inclusive, identifying and retaining a broad range of ideas generated through the process. As the three criteria were applied to the ideas, the terms associated with those concepts were tracked and retained in order to maintain fidelity. The decision was made to include a representative sample of the terms associated with the core engineering concepts to provide a broader contextual perspective on the analysis. However, due to the nature of the analysis, the representative terms are not intended to be conceptually homogeneous. Some terms are essentially synonyms and descriptions, while others represent classifications or types.

Although some of the items on the list are phrased as verbs (i.e., prototyping) or represent identifiable processes (i.e., design), the researchers concluded that these ideas represent a depth of understanding beyond procedural knowledge. The list, irrespective of phrasing, contains ideas that can be generalized from particular instances (i.e., concepts) (Rittle-Johnson & Koedinger, 2009) to the broader context of engineering. Using an example from mathematics, there is a procedural element to subtracting, as well as a conceptual component of understanding subtraction (e.g., what these functions mean within larger contexts, as well as within specific instances). A conceptual understanding is needed to situate ideas within the larger context and certainly extends beyond knowledge of procedures or processes. Instead of following steps, individuals understand what is occurring during and as a result of those steps.

Discussion

The outcomes of the study consisted of much more than a list of core engineering concepts and are thus worthy of discussion to shed light both on the researchers' method and in terms of implications. Although not an original purpose of the study, the process used to identify the concepts raised a number of questions and issues important for secondary level engineering education that the researchers felt necessitated discussion. In addition, the peer debriefing participants were asked to reflect on these issues as they were deemed by researchers as being just as important as the list of concepts.

Problematic Concepts

The research team struggled with two particular themes: (a) problem solving and (b) experimentation. After considerable discussion, consensus was achieved to include experimentation as an engineering concept. The team was, however, unable to achieve consensus on problem solving, even though it emerged as a substantial theme across the five data sets. Engineering activities, such as the clarification of design parameters relative to design constraints, involve solving problems. Thus, at a practical implementation level, a compelling case was made for including problem-solving as a core concept. At a conceptual level, however, problem-solving extends far beyond engineering activity into all realms of human existence. Custer (1995) addressed these issues, classifying problem-solving into three major categories: (a) personal/social, (b) scientific, and (c) technological. Specific to engineering, the concept of problem solving can be seen to represent an overarching concept subsuming design, invention, and trouble-shooting (Custer, 1995) thus confusing its conceptual distinctiveness. Given these challenges, the research team did not include problem-solving on the list of concepts.

As with problem solving, issues were raised by one of the researchers concerning the inclusion of experimentation as a core engineering concept in that the term "experimentation" is closely identified with the scientific method. Within a scientific context, experimentation connotes a specific methodology designed to establish and test hypotheses. Within an engineering context, it deals more generally with informed and incremental trial and error activities involved in making a design work. The argument could be made that the term experimentation is more appropriately associated with science than engineering. However, engineering can be viewed as engineering science, triggered in large part by increased federal funding for engineering research following World War II (Seely, 1993). From this view, experimentation represents a formal analysis of applications of engineering theory. Although the term experimentation may connote other meanings beyond engineering, the researchers decided that experimentation met the inclusion criteria.

Engineering Education Ontology

As evidenced by the discussions of the two "problematic" concepts, the distinctions made to generate a list of core engineering concepts were important to the study. The overarching issues related to this endeavor are linked to the development of an engineering ontology for secondary level education. An ontology is a theory or representative vocabulary about the objects, their properties, and relationships within a specific domain of knowledge (Chandrasekaran, Josephson, & Benjamins, 1999). The identification of a representative vocabulary requires careful analysis and typically begins with clarifying the terminology for coherence and consistency. This involves devising a syntax for encoding knowledge in terms of concepts and relations. This study furthered this process for secondary engineering education in one important area, by identifying core concepts.

As with other domain-specific ontologies (e.g., Borst & Akkermans, 1997; Guarino & Poli, 1995; Newell, 1982), this field's concepts are not discrete and exhibit substantial conceptual overlap. An example is the number of concepts subsumed by or intertwined with engineering design. Functionality, efficiency, systems, and optimization could be considered to be subsumed by design, but in many documents they were also seen as distinct areas of investigation or focus. Design can be considered a primary engineering concept or even a threshold concept. Threshold concepts are distinguished from core concepts in that they are "akin to a portal, opening up a new and previously inaccessible way of thinking about something" (Meyer & Land, 2006p. 3). Engineering design could provide the "portal" for all other engineering concepts and themes appropriate for the secondary level.

Related to defining an engineering ontology, the research team struggled with the extent to which a body of concepts and knowledge can be said to be unique or distinct to engineering. The notion of distinctiveness is problematic for two primary reasons. First, the engineering field is comprised of a spectrum of disciplines, each with a specific set of knowledge. Given these separate fields, the question was raised whether the disciplines share a common and generalizable conceptual core. The second problem with formulating an engineering ontology is that much of engineering is interwoven with knowledge from other academic disciplines, particularly science and mathematics. This leads to the perception that engineering knowledge is essentially the application of knowledge from other disciplines.

These should not be construed as arguments against the existence of an engineering ontology. Rather, we argue that it is critically important to situate discussions of core engineering concepts, such as those identified in this study, within the broader context of an ontology. Furthermore, an engineering ontology should be developed with full realization of the complexity, richness, and challenges associated with such an endeavor.

Social Context of Engineering

The issue of engineering knowledge extends beyond ontology to issues of engineering practice and dispositions. This issue emerged particularly from discussions of the focus group, who encountered difficulty in making these distinctions given the applied and socially grounded nature of engineering. Throughout the analysis of the documents, social issues continually emerged as important to engineering. Primary among these were ethics and interpersonal skills, such as communication and teamwork. As Herkert (2000) pointed out, spurred in part by the standards promoted by ABET, engineering educators "take seriously the challenge of educating professionals who are both technically competent and ethically sensitive" (p. 303). This is not surprising given that engineering is inherently a social construct (Bijker, Hughes, & Pinch, 1989). These contextual issues however are important if core engineering concepts are to be understood in a meaningful way.

Pedagogical & Curricular Implications

Another important issue raised most directly by the peer debriefing participants was the pedagogical and curricular implications of teaching the engineering concepts identified in this study. Many of the panelists questioned how these concepts could appropriately inform curriculum and instruction at the secondary level. However as Donovan and Bransford (2005) indicated, concepts are only a piece of the puzzle. Concepts provide a framework for students to understand factual knowledge and use that understanding in different ways. Concepts do not stand alone, but “take on meaning in the knowledge-rich contexts in which they are applied” (Donovan & Bransford, 2005, p. 6). Thus, the list of concepts generated through this study is not intended to be implemented in isolation or in an abstract manner in the classroom.

Additionally, procedural knowledge should not be taught abstracted from content or concepts. An understanding of process requires the learning of content; each “piece of subject matter is a way of knowing, a way of representing, or a way of solving problems” (Costa & Liebemann, 1997, p. 14). Within a technical domain such as engineering, this view of learning requires that teachers identify the possible knowledge requirements of tasks, ascertain students’ relevant prior knowledge, and provide adequate support for conceptual development (McCormick, 1997). The concepts generated in this study provide a base for understanding engineering that can transfer across contexts. However, the domain knowledge specific to a context is equally important for understanding and reflecting upon the meaning of the concepts. This awareness of the need for conceptual, procedural, and domain knowledge should be reflected in curriculum and specifically addressed in teacher professional development contexts.

Conclusion

Given the framework of an ontological approach for secondary level engineering education, it is important that these concepts be seen as the initial phase of research. As Chandrasekaran, Josephson, and Benjamins (1999) pointed out, constructing an ontology is an ongoing research enterprise. They recommended sharing the knowledge representation language generated through careful analysis with others who have similar needs for knowledge representation in that domain, so as to eliminate the need for replication. This can then lead to building specific knowledge bases for specific situations (e.g., curriculum). It is recommended that this study be used to further that process. Specifically, the interrelationships between the concepts should be more fully explored. An excellent model to help guide this type of work is the *Atlas of Science Literacy* (AAAS, 2001).

This study concentrated on identifying a conceptual base for secondary level engineering education. It should be apparent that this represents a daunting task, triggering a number of conceptual and practical issues. These issues have important implications for education if engineering is to be seriously considered as an integral part of the K-12 curriculum. These issues could significantly impact educational policy at the pre-collegiate level, where the case remains to be made for including engineering content, as well as at the post-secondary level with a growing call for reform in engineering education. Additional areas that warrant further investigation include the possible need for K-12 engineering standards, curriculum, and teacher pre-service and professional development. The central premise of this study is that these issues are best addressed after the conceptual base has been thoughtfully developed.

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Academic Preparedness as a Predictor of Achievement in an Engineering Design Challenge

Nathan Mentzer and Kurt Becker

Introduction

Three influential works have been recognized by the field of technology education as having established a foundation for defining technological literacy: *Standards for Technological Literacy (STL)*, *Technically Speaking,* and *Tech Tally*. A unifying theme emerging from these publications is that technologically literate people are able to function in our modern technological society (Gamire & Pearson, 2006; International Technology Education Association [ITEA], 2000; Pearson & Young, 2002). More specifically, technologically literate people must be knowledgeable, capable, critical thinkers, and decisions makers. The *STL*, published by ITEA, established a formal definition of technological literacy: "Technological literacy is the ability to use, manage, assess, and understand technology" (ITEA, 2000, p. 9). The uniform message is strong—people need to be technologically literate in order to be active, functioning members of our modern society.

Engineering, in general, and engineering design, specifically, are included in *STL*. Including engineering content in technology education curricula necessitates that the field identify successful approaches to teaching engineering at the high school level. Engineering design challenges include the application of engineering principles to solve real world problems with an active, hands-on approach. Incorporating engineering design challenges into formal coursework is one method of teaching the engineering process through practical application. "In brief, available research suggests that these kinds of courses appear to improve retention, student satisfaction, diversity, and student learning" (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 114).

Purpose

The purpose of this study was to determine if a student's academic success, measured by grade point average (GPA) in mathematics, science, and communication courses, is correlated with student change in achievement during an engineering design challenge. Engineering design challenges have been implemented and researched in K-16 environments where engineering principles are applied to solve real world problems. Research shows that engineering design challenges have successfully improved student achievement (Cantrell et al., 2006; Dally & Zhang, 1993; Irwin, 2005; Lentz & Boe, 2004; Marra et al., 2000; Ricks, 2006; Romero et al., 2006; Roselli & Brophy, 2006; Weir, 2004; Yaeger, 2002). Based on this literature foundation, research question guiding this work is: Does a general indicator of previous academic success serve as a

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significant predictor of student learning as measured by an achievement test?

Design Challenges and Achievement

For purposes of this research, an engineering design challenge was defined as a team-based activity in which students engage in solving a real world problem. This approach is initiated by negotiation of the problem definition. Design teams and clients work together to establish their problem and constraints. Information provided by modeling and analysis may illuminate new concerns or possibilities that encourage revisiting the problem definition. This working definition is congruent with that of the Accreditation Board for Engineering and Technology (ABET):

> Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs. (2007, p. 21)

Literature describing engineering design challenges draws on various terms, which, while not synonymous, do refer to similar pedagogical approaches of interest to this study. The terms project-based learning (Dym et al., 2005), active learning (Yaeger, 2002), problem-based learning (Dunlap, 2005; Griffith, 2005; Irwin, 2005), challenge-based instruction (CBI) (Roselli & Brophy, 2006), interactive learning activities (Cantrell et al., 2006), project-driven approach (Dally & Zhang, 1993), design challenge (Romero et al., 2006), cornerstone design (Dym et al., 2005), capstone design (Dym et al., 2005), and team-based project-learning (Marra et al., 2000), all were used to identify literature in the development of a working definition of *engineering design challenge*.

A body of literature was consulted to shed light on the efficacy of engineering design challenges related to student learning. Engineering design challenges have been of increasing interest in the domain of engineering and technology education in recent years. Literature was reviewed from sources including *Technology Teacher*, *Journal of Engineering Education*, *Journal of Technology Education*, *Journal of Industrial Technology Teacher Education*, and the National Academy of Engineering. For purposes of this review, 10 studies have been selected. Selection criteria included the following: (a) publication date of 1993 or later, (b) publication must be peer reviewed, and (c) research must focus on engineering content delivered using the characteristics of an engineering design challenge defined for this study. Literature meeting the above criteria was coded for evidence of (a) research design, (b) student achievement, and (c) study quality.

Combinations of the following keywords were used to identify this body of literature: engineering, high school, middle school, junior high, elementary, technological literacy, standards for technological literacy, engineering education standards, design challenge, problem-based learning, challenge-based instruction, cornerstone, capstone. In addition to the journals mentioned above, the following databases were searched: ERIC via EBSCO Host, Digital Dissertations, Wilson, and Google Scholar.

Table 1
Summary of Study Characteristics and Results

		Research design				Student achievement			Study quality		
Author, year	*n*	Level	Control group	Single group	Measure	Improvement	Sig	SMDES	High	Med	Low
Roselli & Brophy (2006)	300	University	X		Exam	X		.12	X		
Yaeger (2002)	150	University	X		Exam	X		.02		X	
Weir (2004)	78	University	X		Exam	X		.42	X		
Dally & Zhang (1993)	37	University		X	Instructor perception	X					X
Marra et al. (2000)	53	University		X	Perry scheme	X	X*	.65	X		
Irwin (2005)	139	High School	X		Exam	X	X*	.65	X		
Cantrell et al. (2006)	434	High School	X		Exam	X			X		
Ricks (2006)	131	Middle School		X	Exam	X	X*	2.08	X		
Romero et al. (2006)	25	Elementary		X	Instructor perception	X				X	
Lentz & Boe (2004)	25	Elementary		X	Instructor perception	X				X	

* $P < .05$

Ten studies measured student achievement, and each indicated positive change, refer to Table 1. This change was typically measured by an exam, generally, a semester exam at the college level or a unit exam in secondary education. Exams were typically multiple-choice. Some were developed specifically for the research project, while others were traditionally used in the course. Marra and colleagues (2000) differed from the other studies because she used the Perry Scheme as a measure of achievement:

> William G. Perry developed a quantifiable measure of intellectual development from studies of Harvard and Radcliffe college students in the 1960s. The Perry model has a range of “positions” from 1 to 9, each representing an increasingly complex and mature level of intellectual development. Several Perry positions are relevant to college student development and to first-year students in particular. (p. 39)

One study at the university level and both studies at the elementary level used instructor perception of student improvement as their sole indicator of achievement. While instructor perception is a biased and subjective measure, it may be appropriate for consideration on the elementary level as a reasonable means of estimating student understanding of content material, thus, these elementary studies were rated with a medium quality. Instructor perception is not the most appropriate measure of achievement at the university level; therefore, Dally’s 1993 study was rated relatively low on the quality scale.

A typical study at the college level used either multiple sections as control and treatment groups or previous year semester test results as control and current semester test results as the experimental group. Notable results emerged from two of the four high school research studies which considered student achievement. Irwin (2005) conducted a high quality study with control and experimental groups that addressed a complex problem-based learning activity over an eight week span. Results were statistically significant ($p < 0.05$) with an standardized mean difference effect size of 0.65, considered medium (Cohen, 2001, p. 222). Cantrell and colleagues (2006) conducted a study wherein engineering design challenge activities supplemented the standard curriculum, and student performance was compared to statewide statistics on the standardized tests. This study concluded that engineering modules reduced achievement gaps of most ethnic minority groups. Weir (2004) also differentiated her data based on student groups, but she considered an academic top half and an academic lower half in a university engineering course. Her conclusion was that the upper half improved significantly ($p < 0.05$), while the lower half was not significantly ($p > 0.10$) different between the pre- and post-test measures.

In general, these data suggest that learning techniques associated with engineering design challenges are successful in improving student achievement. Specifically, Weir (2004) and Cantrell and colleagues (2006) presented conflicting results. The Cantrell et al. study represented a collaborative effort between the College of Education and the College of Engineering at the University of Nevada and middle school science teachers. The partnership program administered during the 2005 school year was entitled Teachers Integrating Engineering into Science. Three units of instruction were collaboratively developed, which included web-based simulation activities, lesson plans, a design project, and assessment. Results of the assessment were disaggregated by gender, ethnicity, special education classification, and socioeconomic level. The study sample included 434 eighth-grade student participants in approximately 30 classrooms. Mean scores of the study sample were compared with the mean scores of similar groups from the previous year. This study concluded that typically low achieving students, disaggregated by their ethnic minority status, improved more dramatically than typically high achieving students. The study conclusion was that engineering design challenges generally reduce the achievement gap. In contrast, Weir concluded that engineering challenges extend the achievement gap by improving the academically successful students disproportionately to lower achieving students. Weir developed an "active-based-learning curricula," which was implemented in an experimental-control treatment design on the undergraduate level in transportation engineering. Active learning strategies implemented in the experimental group included questioning, problem solving in individual and group settings, and discussions to apply knowledge to "real-life" problems. The control group course was taught one year prior to the treatment group course, consisting of 78 junior and senior students at Worcester Polytechnic Institute (WPI).

This integrative review, generally, concludes that approaches to teaching that include application of an engineering design challenge increase student learning. This conclusion is based on a representative sample of studies that survey students from the elementary years through university studies. Researchers have considered the impact of gender, ethnicity, socioeconomic status, and age of student participants as factors related to student experience during the engineering design challenge. However, limited and conflicting evidence suggests that the academic background of a student may impact their experiences during the engineering design challenge. Technology education students typically represent a broad range of academic backgrounds; therefore, it is essential that we understand how engineering design challenges affect all students from low achieving to high. As technology education classes consider infusing engineering design, a natural concern emerges: does a student's general academic success correlate with student achievement during an engineering design challenge?

The practical significance of this question is based on the nature of the student population in technology education. Technology education students represent a continuum of students ranging from those who are academically successful to those who are struggling in school. If growth in student achievement is uniform and uncorrelated with a general indicator of student success in school, infusing engineering concepts into technology education will presumably be successful for all students. The primary motivation behind this study is the concern that student growth may not be uniform across the range of student academic achievement. If only highly successful students grow, or if they show dramatically higher growth than their less academically successful counterparts, caution must be used when implementing this educational strategy in a class with diverse student abilities.

Methods

To address the research question, data were gathered on student achievement on three occasions. Data were collected in October (pre), December (mid), and April (post). Early October and late April were the earliest and latest data collection dates permitted by the school district policy. Late December was chosen as a midpoint in the school year because the teachers suggested testing before a long winter vacation would provide more accurate results than immediately following the break. Multiple measurements facilitated analysis of changes during the student experience, as well as establishing trends. The multiple measurements lent power to the statistical techniques employed and strengthened conclusions based on data. Trends and changes during the year were compared statistically to a general indicator of each student's academic success. This indicator was an analysis of the junior students' grade point average which includes mathematics, science, and literature/reading scores (communications). Mean scores on the different versions of the achievement test were compared. Reliability and ANOVA testing were conducted on the mean achievement instrument scores using SPSS software version 15.0.0. Longitudinal multilevel modeling was utilized to address the research question. Modeling was conducted with R software version 2.7.0 and the linear mixed-effects models package version 0.99875-9 (Bates, Maechler, & Dai, 2008).

"Achievement tests are designed to provide information about how well test takers have learned what they have been taught in school" (Gay & Airasian, 2000, p. 154). The United States Department of Education (2008) recognizes the importance of student achievement in its mission statement, "ED's [U.S. Department of Education's] mission is to promote student achievement …." Achievement was measured by a test developed in collaboration by the researcher and the classroom teachers. This test was based, specifically, on the goals and objectives of the course, and test items were drawn from validated test banks which included state departments of education and textbook publishers. A pilot test was generated and administered, and the results were analyzed to ensure the validity and reliability of the instrument. Three similar variations of this multiple-choice test were created from the pilot test and utilized during the study.

Previous quasi-experimental research (Cantrell et al., 2006; Dally & Zhang, 1993; Irwin, 2005; Lentz & Boe, 2004; Marra et al., 2000; Ricks, 2006; Romero et al., 2006; Roselli & Brophy, 2006; Weir, 2004; Yaeger, 2002) has established that engineering design challenges are successful in increasing student achievement. To build upon this research base, the current study addressed the potential relationship between students' academic history, measured by GPA, and their experience during an engineering design challenge, as measured by an achievement test.

Research Context

This study was conducted in an urban northwestern city with a population around 200,000. The high school served approximately 1,500 students in grades 9-12. Students enrolled in the elective course “Industry & Engineering Systems” were juniors pursuing a science and industrial technology credit. Ethnic diversity in this course was typical of northwestern communities with white students comprising the majority population. Students from underrepresented populations in engineering and technology comprised approximately 20% of the students enrolled in this elective course. The total enrollment for two sections of this course was 53 on the first day of class and dropped to 41 by the conclusion of the year. Both sections were co-taught by the same instructors with the same content and methods. This course was one year long and combined the concepts of engineering and technology education through two co-requisite classes. Students received a science credit for the engineering as an applied physics class and an industrial technology credit for the materials processing and fabrication class. These students represented a typical class in the northwestern states, including students who are academically high achievers and students who struggle with their performance in school. According to the instructors, students who elected to take this class, generally, have one of two motivations: they were headed to college to be engineers, or they had failed freshmen or sophomore science and needed a credit to graduate. Thus, the academic diversity ensured this study had the potential to reveal trends and correlations across a broad range of student achievers.

The experienced instructors of this course delivered a hands-on experience, which aligned in content and delivery with typical technology education philosophy. The focal point of this course was an engineering design challenge in the spring term. In preparation for the challenge, students experienced a fall semester comprised of lecture and hands-on application of engineering (as applied physics) and metal fabrication technologies. Typical concepts included: motion, magnetism, electric motors, energy, power, forces, electricity, heat, and air pressure, as well as welding, machining, mechanical fasteners, cutting, and bending metals.

The infusion of engineering concepts into technology education courses was a key element of this study. This was accomplished by applying the engineering concepts as related to physics, science, and mathematics to a traditional technology education curriculum, and culminating with an engineering design challenge. The delivery of engineering concepts and technology education concepts was a central phenomenon to this research site. In this classroom, a technology education teacher had partnered with a physics teacher to deliver engineering content in a technology education atmosphere. While team teaching may provide many benefits, it is a rare occurrence. In generalizing the findings of this study, it is assumed that one teacher, skilled in technology education and familiar with engineering design methodologies, may be equally competent in delivering an engineering design challenge to a group of technology education students.

Data Collected

Data were gathered from student high school transcripts. This indicator of general academic aptitude was considered as four factors: cumulative GPA, mathematics GPA, science GPA, and reading/literature GPA. Additional data included a series of three achievement tests. The tests were administered on three occasions during the school year. Longitudinal multilevel analysis techniques were utilized to identify correlations between a student's academic history and change in achievement during the engineering design challenge course.

Quantitative data were gathered on the following variables to address the research question:

Section. This course was offered in two sections. One section was offered in the morning, and the second in the afternoon. Advanced placement courses in the school were offered only in the morning, so students who chose to enroll in advanced placement courses were excluded from enrollment in the morning section. Knowledge of section of enrollment allowed this factor to be controlled and tested for statistical differences.

Special education status. Nearly one third of the students enrolled were being served by special educational accommodations. By identifying this student population, regression analysis was able to control for and test this disaggregated subgroup.

Gender and ethnic diversity. Statistical analysis has a greater chance of accurately detecting differences that exist between groups if the sample sizes of those groups are substantially large. A field-specific definition of minority/majority groups was adopted for this study, which collapsed the gender and ethnic divisions into a larger binary variable. This field-specific definition aligns with the fields of engineering and technology education, wherein Caucasian and Asian males are overrepresented while females and other ethnic groups are underrepresented.

Cumulative GPA. Student transcripts were gathered, and a student's academic success was indicated by a cumulative grade point average during the freshmen and sophomore years. This GPA was based on a 0-5 point scale.*Content area specific GPA.* Student transcripts were disaggregated by mathematics, science, and communication courses. Individual grade point averages were calculated for each area. The school district identified into which category each course fit, and GPA's in these categories was computed on the 0-4 point scale.

Achievement test. Student responses were gathered with a 30-item achievement test administered at three points in the course. Development of the test was discussed in the methodology section, and instrument analysis was discussed with findings for research question one.

Mental motivation. The California Measure of Mental Motivation (CM3) identified five subscales. Each subscale was addressed independently for purposes of addressing the research questions and represents a continuous score on a 0-50 scale in this repeated measure. These subscales were mental focus, learning orientation, creative problem solving, cognitive integrity, and scholarly rigor.

Achievement Instrument Development and Implementation

A suitable achievement test was not available for measuring the extent to which the goals and objectives of this course have been reached. Therefore, an instrument was developed and pilot tested. Schloss and Smith (1999) described a six-step methodology for developing and testing an instrument. Their method was adapted to guide the development of a cognitive achievement test.

Step one was identifying the skills being studied. The researcher, in collaboration with the course instructors, had identified skills taught which relate strongly to engineering, particularly statics and dynamics courses in preparation for application to an engineering design challenge. Triangulation of findings was done through examination of course material including syllabus, handouts, worksheets, and researcher observation.

Step two involved enumerating skills wherein the skills identified were broken down into smaller elements which could be measured. The researcher differentiated between conceptual and mathematical understanding of the engineering related materials.

Step three included establishing test specification, skills, and subskills that were identified, specifically, for this test and a multiple-choice format was selected. The pilot test was administered the year prior to research beginning with a comparable group of students.

In step four, test items were developed. In order to reduce bias and increase reliability, test items were selected from external sources rather than researcher developed. These external sources included released test items from state departments of education from a comprehensive survey of 50 states. The other source of test items was publishers of texts pertaining to technology education, engineering, and physics. Many of these publishers supply test banks to teachers for classroom use matching the needs for this study.

Step five focused on a scoring procedure. As a result of test specification, step three, a multiple-choice test, includes an answer key. The answer key was researcher generated based on the test sources and course instructor verified.

The final step, six, included evaluating reliability and validity. A pilot test was assembled and administered to students during the 2006-2007 spring term near the conclusion of the school year. These pilot students were expected to be comparable to the students participating in the main study, since they were in the same courses with the same instructors. The pilot test was administered in the late spring just as the posttest was in April of the 2006-2007 school year. A Kuder-Richardson 20 (KR-20) statistical analysis was used to refine the pilot test and develop a final version of the exam. As explained by Gall and colleagues (1999):

> The KR-20 formula is a method of calculating the reliability of a measure containing items that are scored dichotomously (e.g., correct-incorrect). A high reliability coefficient (i.e., approaching 1.00) indicates item consistency, meaning that individuals who choose one incorrect). A high reliability coefficient (i.e., approaching 1.00) indicates item consistency,

> meaning that individuals who choose one answer to some items tend to choose the same answer to other items. Correlation coefficients between .73 and .86 indicate that the course examinations have good, but not perfect, reliability in terms of the consistency with which they measure students' course-related understanding and ability. (p. 260)

Following the pilot test, three similar versions of the instrument were developed. Each of these versions has the same test specification, targeting the same skills. Each test version has a combination of alternate questions, modified questions, and a few repeated questions. Inherent in the fact that the tests are different, student mean scores varied slightly. To ensure that changes over time were student changes rather than instrumentation changes, a randomized test administration was followed. During the administration of each test, one-third of the students received each version of the test. At the conclusion of the term, all students had taken each test version, but not in the same order. Students were randomly assigned to groups for the purposes of test taking. Each group took a different version of the exam during each testing session as shown in Table 2.

Table 2
Procedures for Administrating Achievement Test

Test version	Student group 1			Student group 2			Student group 3		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
A	x					x		x	
B		x		x					x
C			x		x		x		

The 43-item pilot test was analyzed using two measures, the Kuder-Richardson 20 (KR-20) and an indication of the relative difficulty of each item. The test was reduced from 43 pilot questions to a 30-question test and became version A. The final KR-20 for version A was 0.781. From version A, additional questions, which were considered comparable, were developed to form versions B and C. These additional questions fell into one of three categories: original, modified, and repeated. Original questions were utilized as found from the test banks. Modified questions were based on original questions but modified from their original form for one of two reasons: (a) to make them relevant and (b) to use them again in another version. A typical example of a question modified to be more relevant dealt with distance, velocity, and rate calculations and was changed to include locations proximate to the research location. Another example of a typical modified question would be one that solicited students to identify which gear ratio provides the most torque changed to most speed or least speed. In some instances, questions were repeated verbatim since comparable questions were not located and modifying the format of the question was impractical.

Data Analysis

Data analysis was conducted using longitudinal multilevel modeling techniques. This analysis allowed multiple predictor variables to be analyzed in this repeated measures design for prediction of student achievement. "…applications of multilevel models are longitudinal research and growth curve research, where a series of several distinct observations are viewed as nested within individuals…." (Hox, 2002, p. 1). Predictor variables included high school grade point average (general indicator of academic history), time, and section. The main predictors of concern were the grade point averages for each academic area (science, mathematics, and communications). This predictor served as a variable with which a correlation was identified with the outcome variables. The predictor of time was critical since it had three time points, pre (October), mid (December), and post (April). Change in students was expected as a result of time, and, therefore, our knowledge of the time point served to establish a growth trend. While two sections of students have enrolled in this course, membership in a section cannot be assumed as random chance. Scheduling conflicts may have impacted student enrollment rather than random chance alone. The researcher has noted that an advanced mathematics class conflicted with one of the sections of this course. To control for these factors, the section membership was recorded and entered into the model. The ability to control for these differences strengthened the model by reducing variability.

Hox (2002) commented on the application of multilevel analysis in repeated measures designs:

> Longitudinal data, or repeated measures data, can be viewed as multilevel data, with repeated measurements nested within individuals. In its simplest form, this leads to a two-level model, with the series of repeated measures at the lowest level, and the individual persons at the highest level. (p. 73)

In this study, as suggested by Hox, level one was the three time points. Level two was the individual level including three predictor scores (mathematics, science, communications), the class section, and achievement scores. In the modeling strategy, the power of this statistic was increased by having multiple data collection points rather than only a pre- and post-test design (Hox, 2002).

Efforts were made to ensure that all students participating in the study were present during the testing sessions. A 2-week stay at the research site facilitated data gathering from all students. In the rare event that a student was not available during this time, multilevel analysis results were not jeopardized by missing cases. The data available were used and contributed to the model regardless of one or more missing data points.

In the modeling process, the main effects of predictors were considered in addition to their interactions with time. Interactions between main effects were analyzed including the effect of academic history and time. Slopes and intercepts of main effects and interactions were interpreted. This analytic modeling strategy facilitated an understanding of the relationship between a student's general academic history and changes in achievement during an engineering design challenge.

Results

Two sections of students participated in this study by enrolling in two co-requisite classes. The total sample size was 53 students. Due to attrition, 41 students completed the year long course. Table 3 shows demographic data summarizing the participant sample. Student enrollment was evenly split between both sections, with dropout rates consistent between sections. Female enrollment in October was 9.50% but representation increased to 12.20% as a result of male dropout. Cumulative GPA had an overall mean of 2.09 on a scale of 0-4. Changes in student enrollment over time increased GPA, which resulted from a disproportionately higher dropout rate of students with low grade point averages. While mean GPA increased, this change was not statistically significant, F (2,140) = 0.21, p = 0.808.

Table 4 compared demographic data on the study participants and the high school population. The percentage of students served by special educational accommodations in this study was 30.00% which is approximately 2.50 times that of the high school. Ethnic diversity data was not reported by all participants. An average of 12.50% did not report. Of the students who did report identifying themselves with an ethnic background, approximately one-quarter of them (24.50%) were not Anglo American, Caucasians. This proportion was just a few percentage points higher than the school statistic of 21.90%. Data were not collected on limited English proficiency or free and reduced lunch specific to this study; however, the school reported 1.40% and 39.00%, respectively.

Table 3
Demographic Data on Participants

	October (Pre)	December (Mid)	April (Post)	Average
Study *n*	53	50	41	48
Section:				
1	28	26	21	25
2	25	24	20	23
Gender:				
Female	5	5	5	5
Male	48	45	36	43
Special education Accommodations	15	15	13	14
Ethic status:[a]				
Majority	32	32	31	32
Minority	11	11	9	10
Unreported	10	7	1	6
Mean cumulative GPA[b]	2.04	2.08	2.16	2.09

[a] based on student self-identification.
[b] based on transcript data grades 9 and 10, GPA scale 0-4.

Table 4
Demographic Data Comparing Study and School Percentages

	High School[a]	Study
Special education accommodations	12.60	30.00
Ethnic diversity:		
Majority	78.10	75.50
Minority	21.90	24.50
Limited English proficiency	1.40	NA
Free and reduced lunch	39.00	NA

[a] based on school district publication

The research question addressed the students' change in achievement during an engineering design challenge. Figure 1 shows student performance on the achievement tests. Mean scores dropped between October (70% correct) and December (66% correct) but showed gains between December and April (72%

correct). Table 5 shows variations between versions for each test administration. Pretest variation was very small, 0.20% between versions. Variation increased in December to 11.10% and dropped a few percentage points to 8.20% in April. ANOVA tests show no statistically significant differences between the versions at each time point (October: F (2,49) = 0.00, p = 0.999; December: F (2,47) = 1.67, p = 0.199; April: F (2,38) = 1.04, p = 0.364).

Figure 1. Mean Achievement Scores Compared across Multiple Time Points

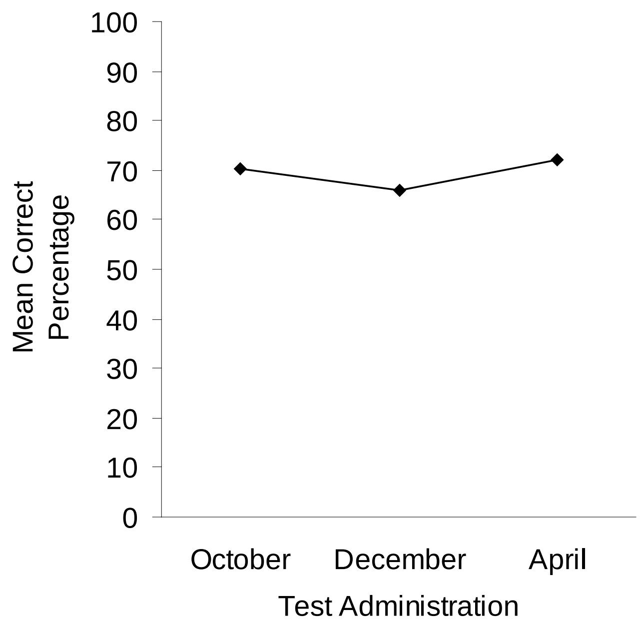

Table 5
Descriptive Data for Achievement Tests by Administration

	M (percent correct)	*SD*	*n*
October			
A	70.20	14.00	17
B	70.20	16.00	19
C	70.40	13.90	16
Average[a]	70.20		
December			
A	61.80	23.20	15
B	72.90	15.30	17
C	63.00	19.40	18
Average[a]	66.00		
April			
A	75.70	13.60	14
B	74.60	15.50	11
C	67.50	19.90	16
Average[a]	72.20		

[a] Average is weighted.

Hypothesized model. A two-level longitudinal multilevel model assessed the effects of cumulative grade point average, grade point average in mathematics, science, and communication courses, course section, special education accommodation, minority status, and mental motivation as measured by the CM3 assessment on achievement. It was expected that a potential correlation existed between change indicated by the achievement test and GPA. First-level units were repeated measures within individual study participants. Data from 144 achievement tests were considered for analysis. Second-level units were 53 participants in this study. In the hypothesized model, individuals and time are declared random effects to assess variability among individuals within time points, as well as variability among time points. Also, one of the predictors, mental motivation, was declared a random effect, reflecting the hypothesis that there would be individual differences in the association between mental motivation and achievement.

Longitudinal multilevel modeling of achievement. A main-effects-only model was created and tested against a main-effects model that included interactions of time and each predictor. Significance testing was conducted using likelihood ratio tests comparing the model fit using R. Significant interactions were included in a model, which was then reduced in a top-down approach. A reduction technique was employed where the least significant predictors were removed one at a time. Each model iteration was compared to the previous model using a likelihood ratio test to determine if it was statistically different. The final model was not significantly different than main–effects-only model, $\chi2$ (7, N = 123) = -193.466 + 198.118 = 4.6526, $p > 0.05$. Statistically significant predictors in this model are special education status, GPA in previous science courses, and the CM3 subscale of creative problem solving. Special education students tended to underperform their peers. Students who maintained a higher science GPA, and also students scoring higher on creative problem solving, tended to demonstrate an increase in achievement scores. A student's status as an underrepresented population member and CM3 subscale cognitive integrity were included in the model but were not statistically significant. No significant interactions were discovered with any predictor and time, which indicates that no significant changes over time were discovered relative to the predictors. Predictor data is shown in Table 6. Note slope estimates were reported as items correct on the 30-question achievement test.

Table 6
Longitudinal Multilevel Modeling of Achievement Results

Variable	Name	Variance	*SD*	Scale	Estimate	Std. Error	*t* value
Random effects							
STUDY_ID	(Intercept)	12.56	3.54				
Residual		5.79	2.41				
Fixed effects							
Intercept					12.57	2.41	5.21
Special education				0,1	-2.90	1.36	-2.13
Underrepresented population				0,1	-2.01	1.26	-1.60
GPA science				0-4	1.24	0.60	2.09
Creative problem solving				0-50	0.14	0.05	2.57
Cognitive integrity				0-50	0.11	0.06	1.93

Note: Number of obs: 123, groups: STUDY_ID, 43.

Discussion

In this research, student achievement was significantly correlated to science GPA, but not significantly to mathematics or communication GPA. Therefore, a student participating in this study was likely to perform better on the achievement test if their science GPA was higher. The differences are not only statistically significant, but they are practically significant. To quantify the practical significance, consider an example: the mean scores in October were approximately 70% correct, and the average science GPA was nearly 2.00. A typical student who failed previous science courses would tend to score 10% lower, or about 60% in this example. Conversely, a student who earned a 4.0 GPA in science would tend to score about 10% higher, or about 80%. Knowledge of previous performance in science lends substantial prediction capabilities to a student's performance in this achievement test.

Previous performance in mathematics and communications courses did not provide significant prediction capabilities in the modeling. This indicated that students who performed poorly in mathematics or communications were not disadvantaged significantly over their higher GPA peers. Although mathematics and communications GPAs were not statistically significant predictors, a positively correlated trend was noted. Students with a higher mathematics or communication GPA tended to perform better on the achievement test. Special education status provided significant prediction in the model. Special education students tended to score about 10% lower than their regular education peers. While this number is statistically significant, the practical difference was questionable. Special education study participants represented nearly one third of the study sample. This proportion was approximately 2.5 times greater than the high school demographic. Generally speaking, special education students received additional educational services to be successful in school. However, in this study, they performed only about 10% under their peers without support on the test.

Achievement score changes over time were not significantly correlated with science, mathematics, or communication GPA. This indicated that slope modeling for higher and lower GPA students does not show statistically significant changes over time. Therefore, higher GPA students were not advantaged or disadvantaged over time in comparison to their lower GPA peers. This interpretation needs to be considered conservatively as class mean scores did not change significantly over time. The lack of significant mean change over time potentially indicated students did not learn (in a measurable sense) during this course. Alternatively, the achievement instrument may not have fully captured the essence of learning which did occur but was not measured. While speculation regarding why students did not show improvement over the seven month study was non-conclusive, the scores for lower GPA students did not drop significantly. This does indicated that lower GPA students remained active in their participation in course experiences which included the achievement test. Cantrell and colleagues (2006) and Irwin (2005) measured high school student achievement growth, and both indicated improvement, while only Irwin indicated significant improvement.

Student status as a member of an underrepresented population group improved the model fit statistically, but was not a statistically significant predictor. The mean difference between majority and underrepresented populations was of interest, but due to a large variance and relatively small mean difference, inclusion in the model could have been attributed to chance and chance alone. Cantrell and colleagues (2006) conducted a study wherein engineering design challenge activities supplemented the standard curriculum, and student performance was compared to statewide statistics on the standardized tests. Cantrell's study concluded that engineering modules reduced achievement gaps of most ethnic minority groups. Our study indicated ethnic minority groups underperformed their majority peers. This difference, noted in mean scores, was not statistically significant. Change over time does not support Cantrell's finding that the achievement gap was reduced, but it does suggest that the achievement gap was not increased significantly.

Weir (2004) differentiated data based on student groups by considering an academic top half and an academic lower half in a university engineering course. Her conclusion was that the upper half improved significantly ($p < 0.05$), while the lower half was not significantly ($p > 0.10$) different between the pre- and post-test measures. This research indicated that using science, mathematics, and communication GPA as indicative of students' academic nature, students improved slightly more over time if their GPA was higher. This lends some support to Weir's conclusion, but differences based on GPA over time were very small and could be attributed to chance and chance alone.

The field of technology education embraces the importance of technological literacy and caters to an academically diverse audience of student learners. Integrating engineering design into the curriculum addresses the Standards for Technological Literacy and broadens student understanding of our designed world. This study provided an approach to operationalizing the definition of engineering infused into technology education. In this example, students participated in two co-requisite classes. Each class was essentially a standalone course in the fall, one focused on engineering as applied physics and the other material (typically metal) fabrication techniques. The set of learning experiences implemented in the fall in both classes prepared students with foundational knowledge from which they could begin to design, fabricate, test, and redesign during the spring term when the two classes merged into one longer block of time. The use of electric cars as a design challenge provided a problem on which engineering design was applied.

Results from this study indicate that while achievement gaps exist, these gaps are not widened while introducing engineering design concepts into a technology education classroom. Special education students performed poorly on the achievement test as did lower science GPA students, however, growth among these groups was not statistically different than their peers. Thus, engineering design infused into technology education does not disadvantage student growth as measured by an achievement test over time.

In taking full advantage of the engineering design process, an understanding of mathematics and science (physics in this study) was necessary. Technology education teachers should pursue a strong background in mathematics and science. Physics was the most overt science content exploited in this study; however, other science principles may be appropriate. As an example for this design challenge, a teacher with a strong understanding of fluid dynamics may have encouraged the students to think more about aerodynamics. This may have resulted in students' designing their bodies and frames differently to optimize speed. Therefore, a broad teacher understanding of mathematics and science will provide opportunities for deepening student understanding of the system behaviors through explanation and relevant hands-on application. While naive understandings of mathematics and science will limit technology teacher potential, a lack of understanding does forecast impending failure. Teachers may choose a few aspects of a particular engineering design challenge with which they are (or will become) familiar, and other aspects may be left to trial and error approaches. Where areas of teacher weakness exist, opportunities for professional development abound. However, in the busy teacher workday, other support may be found through collaboration with science and mathematics teachers, industry professionals, higher education partnerships, and knowledgeable parents.

Technology teachers need to be prepared to reinforce absent science concepts, which are relevant to the task at hand, when delivering an engineering design challenge. The introduction (or review) of relevant mathematics and science concepts may be in a series of small activities that build up to the challenge or in a “just-in-time” format to meet the needs of the learners. Mathematics and communications are important academic areas, and, generally, showed positive correlations with outcomes measured in this study. The correlations with mathematics and communications were not statistically significant, which may be related to the focus of this particular design challenge, not necessarily representative of all design challenges.

Student motivation was critical to maintaining and managing a successful learning environment. Motivated students tend to make a more diligent effort to acquire new material and apply their conceptual understanding to problems at hand. In this study, students formally began designing their solutions to the engineering design challenge in January. As early as March, student teams were beginning to race their cars. Races were typically hosted by local schools and were held nearly every weekend. This schedule impacted learning in the classroom by facilitating an iterative design process. Students would typically race their cars on Saturday, make improvements or modifications during the week, and then race again the following week. This iterative form of testing allowed teams to make changes to their car and discover firsthand the results of those modifications. By virtue of the tight timeframe, teams generally raced the first few races without a car body. But, when the car was functional, they focused efforts of developing an aerodynamic body. Thus, inadvertently, students experienced the impacts of each improvement to their cars as the designs evolved over time. This iterative process provided learning opportunities, but also motivated students through the excitement of testing their renewable energy vehicle. Therefore, as teachers incorporate design challenges, students need the opportunities to engage in the iterative process of design, test, redesign, and test again for the purpose of discovering the impact of their modifications, as well as being motivated by successful experimentation.

Future Research

Clarity of operationalizing engineering design appropriate for technology education is an area for future research. Engineering design was defined for this study through a synthesis of relevant literature and research site practice. Presented in the findings section are data describing the context of this research. The developmentally appropriate nature of determining the extent to which engineering design related activities and lessons are utilized in this eleventh grade classroom was based solely on the participating teachers' discretion. Therefore, future study may enhance the field's understanding of what constitutes developmentally appropriate engineering design curricula in a technology education environment.

This study established correlations between predictors and outcome variables but must stop short of inferring causality. Additional research should pursue casual effects based on this research foundation. Experimental designs with control and treatment group should be conducted in a variety of classrooms. Engineering design presented here was applied to the Electrathon America challenge and could be extended to various other engineering problem solving opportunities. These experimental designs should vary in duration, from unit sized formats lasting a few weeks to semester long challenges such as this one. This study was potentially unique in that two teachers were participating under one syllabus, teaming their efforts focused on a common goal. While some school districts offer incentives for teachers to develop their cross-curriculum connections in a team approach, many do not. Experimental studies should be conducted to demonstrate differences between team teaching environments and more typical one-teacher classrooms. Longitudinal data may be gathered following students who participated in a design challenge study. Students in the control and treatment groups may be followed over a number of years to assess the impact in postsecondary education and career choices.

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EnviroTech: Enhancing Environmental Literacy and Technology Assessment Skills

Mary Annette Rose

It is no coincidence that many of the *Grand Challenges for Engineering* (National Academy of Engineering, 2007-2010)—such as carbon sequestration—address environmental problems that were precipitated by human inventiveness and engineering achievements. Although we recognize our dependence upon environmental processes to provide essential resources and ecosystem services, such as food and air purification, our understanding of the interconnections between the environment and our technological activities has often been insufficient to predict technological impacts upon the environment. As evidence mounts that our technological actions threaten the viability of ecosystems and public health (e.g. U.S.EPA, 2010a), it is imperative that all citizens improve their environmental literacy and technology assessment skills if we are to break this untenable cycle and make progress toward sustainability.

As characterized by *Excellence in Environmental Education: Guidelines for Learning (K-12)*, a standards project of the North American Association for Environmental Education (NAAEE, 2010), environmental *literacy* refers to a unique combination of knowledge and skills that enables informed decision-making. These essential attributes include knowledge of environmental processes and the environmental consequences of human action, inquiry and analysis skills, and an ability and commitment to act. Technological literacy—"the ability to use, manage, assess, and understand technology" (ITEA, 2000) — is the explicit mission of technology education programs in the U.S.. As articulated within *Standards for Technological Literacy* (ITEA, 2000), two content standards and their associated benchmarks mutually support environmental education guidelines (NAAEE, 2010), including:

5. Students will develop an understanding of the effects of technology on the environment.
13. Students will develop the abilities to assess the impact of products and systems. (ITEA, 2000)

Without interdisciplinary understandings and assessment skills that stress the interconnectedness of the human-built and natural environments, teachers and students of technology will not be able to understand or assess how these systems interact and influence each other.

Including the aforementioned standards within *Standards for Technological Literacy* (STL) marked new content for technology education (TE) curriculum. Daughtery's (2005) study of technology teacher educators indicates widespread support for these standards and some graduate programs have included relevant coursework (e.g., Rose & Flowers, 2008). As with most curricular change

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initiatives, the most critical need rests with the estimated 26-36,000 practicing technology teachers (Dugger, 2007) who may not have had formal education related to these standards.

Unfortunately, practicing technology teachers have had few opportunities to build sophisticated levels of environmental literacy, especially within their formal science coursework. McAlister's (2005) survey of 24 technology teacher preparation programs in the U.S. indicated that preservice technology teachers take an average of 8 credits of science (range = 6 to 13) with physics (10 of 24) being the most commonly reported requirement, followed by chemistry (4), and biology (3). Only single occurrences of environmental, life, natural science, and biotechnology were evident in these survey results. This combined evidence suggests that practicing technology educators need professional development opportunities to enhance both their environmental and technological literacy. The EnviroTech Project, made possible by a grant by the United States Environmental protection Agency and Ball State University, aimed to address this need.

EnviroTech Mission and Goals

EnviroTech was a web-enabled professional development project, which occurred in the spring of 2009. This document describes the results of EnviroTech in terms of the impact it had upon a cohort of 19 practicing technology teachers. The mission of EnviroTech was to develop (1) understandings of environmental processes and systems; (2) skills for identifying, analyzing, and assessing the impacts of technology upon the environment; and (3) skills in the use of guided inquiry, an instructional strategy where teachers structure and scaffold the examination of problems and gaps in knowledge. The semester-long project facilitated guided inquiry into two essential questions:

- How might replacing incandescent lamps with compact fluorescent lamps (CFL) impact the environment and society?
- What strategies might individuals and communities use to reduce the negative impacts of replacing incandescents with CFLs?

The adoption of CFLs is a fruitful technology assessment theme because it is conceptually rich in terms of the environment, timely (Energy Independence and Security Act, 2007), accessible to students, relevant to personal health and safety, and relevant to civic responsibility. It is the mercury within CFLs—an average of 4 mg per bulb (Energy Star, 2008)—and the emissions of mercury from coal-fired electricity production—an estimated 0.012 mg/kWh (Energy Star, 2008) —that has the greatest potential for impacting the environment and human health. Mercury, like carbon, naturally cycles through the atmosphere to the soils and water through a process known as mercury deposition. Once back on earth, mercury can be transformed to methylmercury through microbial activity and bioaccumulate in fish and the animals that eat fish, including humans (U.S.EPA, 2010b).

These results may inform professional development providers about the efficacy of this distributed model and provide practicing teachers with instructional models that simultaneously address environmental and technological literacy goals.

Methods

As described below, the one-year EnviroTech project included four distinct phases.

Planning, Recruiting, and Developing

During the fall semester of 2008, project staff planned five web-based seminars, recruited teachers, and developed a web-based portal (http://envirotech.iweb.bsu.edu), evaluation instruments, and teaching and learning resources. Several instructional materials—an instructional guide and a web-based tool for generating a force field analysis—were developed and provided to participating teachers. The instructional guide, *Impacts of Technology on the Environment: Resources for Decision Making* (Rose, 2009), employs life cycle assessment as a framework for teaching and learning. The document is arranged into background information for the teacher, 10 activity sheets for students, and worked examples.

A call for participation generated 26 applications from interested technology teachers; 19 teachers, including 6 females, completed the semester-long project. Teachers resided in nine different states, located within the Eastern Seaboard/Mid-Atlantic (7) and Midwest (7) regions, followed by the South (4) and West (1). The average teaching experience was 15 years (range = 2-34 years). Fifty-three percent (n = 10) were middle school teachers who taught introductory technology courses (e.g., Inventions and Innovations or Technology Today); high school teachers (32%) and an elementary teacher (5%) also participated in the project. Most teachers (74%) had never taken an ecology or environmental studies course. On a 3-point scale from no competence (1) to extremely competent (3), the average rating for teaching others about environmental impacts of technology was 1.8, interpreted as less than competent. However, 18 of 19 teachers reported having formal educational experiences addressing technology assessment; the average competence rating regarding technology assessment was 2.2, interpreted as competent.

Webinars

During the spring of 2009, teachers met once per month for five virtual webinars using *IHETS Interactive*, a technology service of Indiana Higher Education Telecommunication System based upon Adobe Connect web conferencing software. These 70-80 minute webinars enabled synchronous audio and video communications among the hosting instructor, participating teachers, and three guest speakers who were experts in solid waste, environmental education, mercury pollution, and technology assessment. Webinar topics included life cycle assessment, guided inquiry, the mercury deposition cycle, recycling of lamps, hazardous waste collection systems, and forecasting.

Guiding Student Inquiry

All participating teachers planned and implemented a guided inquiry experience with their students, which also addressed the aforementioned essential questions. Sometime between April and June of 2009, about 420 students from 26 separate classrooms participated in EnviroTech inquiry activities. As indicated in Table 1, the largest group of participants was the 10 teachers who delivered instruction to 244 middle school students (6-8th graders).

Table 1. *Teachers and Students by School Level, Sex, and Courses*

Level	Teachers			Students # (%)	Courses
	Male	Female	TOTAL		
High School	7	1	8 (42%)	136 (32%)	Engineering Processes Engineering Applications Geospatial Technology Digital Electronics Technological Design Technological Issues Foundations of Technology
Middle School	5	5	10 (53%)	244 (58%)	Inventions and Innovations Technology Today Introduction to Technology Computer Technology The Environment and You Communications Systems
Elementary	1		1 (5%)	40 (10%)	Technology
TOTALS	13 (68%)	6 (32%)	19 (100%)	420 (100%)	

As one would expect from an inquiry approach to instruction, the nature of these teacher-planned instructional experiences was quite varied. A content analysis of teachers' end-of-project teaching portfolios was conducted to identify the types of analytical strategies they integrated into instruction. Teachers guided students through experiments with lamps (68%), calculations of the efficiency of lamps (32%), and the analysis of data using graphs and charts (32%) and life cycle analysis (26%). Only two teachers (11%) explicitly noted the use of force field analysis or forecasting as it applied to predicting the potential mercury released into the environment from coal-generated electrical power. Some classes documented their inquiry by producing videos or developing posters about the proper way to dispose of CFLs. Others conducted a home or school inventory of lamps or surveyed parents, neighbors, and custodians to discover the disposal practices for mercury-containing lamps. Teachers invited guest speakers (a lamp recycler and a physician) into their classrooms or took students on a field trip to a fish hatchery to highlight mercury deposition and bioaccumulation in fish. In one instance, a school's Technology Student Association chapter entered their CFL inquiry activity in the Environmental Challenge competition at the state level and took first place.

Insights from the Evaluation Study

Evidence from pretests provides insight into how EnviroTech teachers supported environmental literacy within their classrooms. Comparison of pre- and post-tests also helped gauge the impact of the EnviroTech project upon teachers' knowledge, instructional practices, attitudes, and behaviors. Data were analyzed using SPSS 16.0 and Wilcoxon Matched-Pairs Signed-Rank test, a nonparametric procedure for repeated measures that does not make assumptions about the normality of distributions.

Impact on Teachers: Knowledge Changes

The knowledge assessments, including 18 multiple-choice items, examined teachers' understandings of environmental processes, technological concepts, and technology assessment. Pretest percentages indicated low preexisting understandings on environmental and technology items, including items related to the transformation of mercury into methyl mercury, mercury deposition, retorting, energy efficiency of lamps, and the reason for replacing incandescents with CFLs. In contrast, teachers' knowledge of disposal issues related to mercury-containing lamps was high. For example, over 80% of teachers classified CFLs as household hazardous waste, indicated how to properly dispose of mercury-containing lamps, and correctly identified when mercury was likely to be released into the environment.

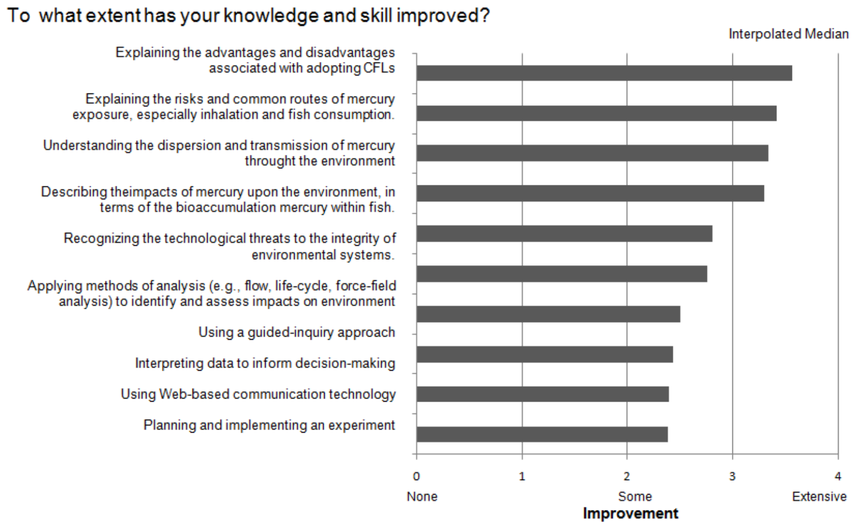
When all knowledge items were aggregated, a Wilcoxon Signed-Rank test indicated statistically significant differences ($Z = -3.839$, $p < .000$) between pre- (Median, *Mdnn* = 11, Range = 9) and post-assessments (*Mdn* = 15.4, Range = 8). As shown in Table 2, the percentage of correct responses increased on all 18 knowledge items, with the highest gain (95% difference) occurring for the item that assessed reasons for replacing incandescents with CFLs. Positive gains, albeit more modest, were seen for other items, including those which measured environmental understandings, such as the transformation of mercury into methyl mercury through bacterial action, the mercury deposition cycle, and bioaccumulation.

Table 2. *Comparison of Knowledge Items on Teachers' Pre- and Post-Assessments*

Items	% Correct **Pretest** N= 19	% Correct **Posttest** N=19	Differ-ence
Technological Knowledge			
Reason for replacing incandescents with CFLs	5	100	+95
Largest source of mercury emissions: coal-fired electricity	42	95	+53
Retorting: Process of reclaiming mercury from lamps	5	53	+47
Energy efficiency of lamps	16	47	+32
How a CFL works	63	89	+26
When CFLs most likely to release mercury into environment	84	100	+16
How to properly dispose of mercury-containing lamps	84	100	+16
CFLs are household hazardous waste	89	100	+11
How most electricity is generated in U.S.	84	89	+5
Environmental Knowledge			
Mercury transforms into methyl mercury through bacterial action	5	58	+53
Mercury deposition	21	68	+47
Bioaccumulation of mercury up the food chain	58	100	+42
Human exposure to mercury through consumption of fish	63	95	+32
Mercury's impact on human health	68	95	+26
Most vulnerable population to mercury exposure	84	95	+11
Technology Assessment (TA)			
Technology assessment as a set of methods	47	58	+11
Results of a TA are used to inform policy and adoption decisions	63	74	+11
Inquiry			
Inquiry is asking questions, gathering and analyzing data, and reaching a conclusion	84	95	+11

Positive knowledge outcomes were also supported by teachers' responses to attitudinal questions. As shown in Figure 1, teachers reported substantial-to-extensive knowledge gains in regards to the advantages and disadvantages of CFLs (*Mdn* = 3.5, Range = 2), routes of mercury exposure (*Mdn* = 3.4, Range = 2), mercury deposition (*Mdn* = 3.3, Range = 2), and describing the impacts of mercury upon the environment in terms of the bioaccumulation of mercury in fish (*Mdn* = 3.3, Range = 2).

Figure 1. *Self-reported improvements in teacher knowledge and skills*



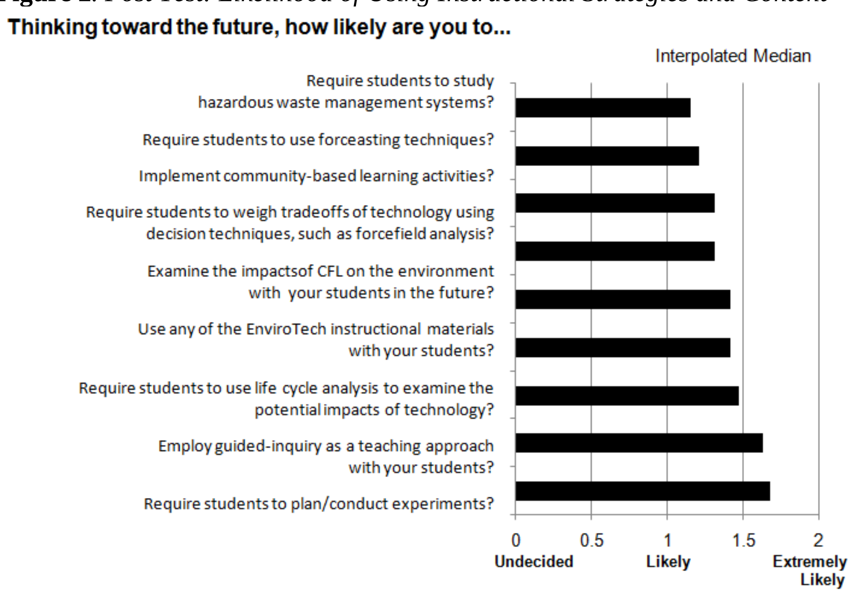
An open-ended question was also posed to teachers: "What is the most important thing you have learned about assessing the impacts of technology on the environment?" The most frequent response related to the value of taking a life cycle or systems approach to teaching about impacts. One teacher wrote, "[we] must consider overall impact, not of the device after manufacture and during its useful lifespan alone, but impacts surrounding creation and final disposition of the device as well." Another teacher pointed out the importance of data-based decision-making when he stated "teaching students to use data collection and analysis in every phase of a product life cycle will enable them to make much more accurate asses[s]ments and informed decisions about technology."

Impact on Teachers: Instructional and Curriculum Practices

In an open-ended pretest question, teachers were asked to "identify and describe the strategies you have used to help students assess and understand the connections between technological decisions and environmental impacts." Class discussions (47% of teachers) were the most commonly cited instructional strategy, followed by literature research (37%), reflection activities (16%), and reports/presentations (16%). To probe directly at the teaching practices advocated by the EnviroTech project, teachers were also asked to identify the frequency that they used guided inquiry, experimentation, forecasting, decision-making techniques, and life cycle assessment. Teachers' reported use of guided inquiry (*Mdn* = 3-5 times/semester) and experimentation (*Mdn* = 3-5) was high with only 11% and 16% of teachers, respectively, reporting that they have NOT used these strategies in the past year. Reported use of forecasting (*Mdn* = 1-2) and decision techniques (*Mdn* = less than 1), such as force field analysis, was lower with 37% and 53% of teachers, respectively, reporting that they have NOT used these strategies.

To better gauge the impact of EnviroTech, items on the posttest asked teachers to think toward the future, and indicate how likely they would be to use these practices with their students. Response items were on a 5-point scale, ranging from extremely unlikely (-2), undecided (0), to extremely likely (+2). As shown in Figure 2, average reported intentions ranged from likely to extremely likely for all instructional strategies, including guided inquiry, experimentation, life cycle analysis, decision techniques, and community-based learning. Given that teachers' past usage of forecasting techniques and decision techniques were low, their intentions to use forecasting techniques (*Mdn* = 1.3, Range = 2) and decision techniques (*Mdn* = 1.4, Range = 2) suggest a positive impact of the project.

Figure 2. *Post Test: Likelihood of Using Instructional Strategies and Content*



Additionally, an open-ended question was asked; "What is the most important thing you have learned about the guided inquiry approach to instruction?" Teachers pointed to the value of posing relevant essential questions and requiring students to gather and analyze evidence. One teacher wrote, "students feel the responsibility inherent in pursuing answers to questions that the adults in their lives have yet to answer as well. We need to engage learners in the pursuit of these answers and let them know that we are counting on them to do their best to help find solutions." Another stated, "The guided-inquiry approach has the ability to deepen student engagement in a significant way. By asking students to gather the data that they use to base their decisions, instructors give their students the chance to discover, question, and analyze, all of which are higher-level thinking skills."

Environmental Concepts and Principles

Responses from the pretest indicated that opportunities to build environmental literacy within technology courses are inconsistent. When asked how strongly teachers agreed or disagreed with the statement "My students have the opportunity to develop environmental literacy," the average response was tending to agree (*Mdn* = .64, Range 4) on a 5-point scale, where +2 = strongly agree, 0 = neutral, and -2 = strongly disagree. However, when asked to "list the environmental concepts and principles that you address in your technology courses," 21% of teachers indicated that no environmental concepts and principles were taught. A thematic review of the teachers' responses to this question yielded five main themes, including ethics/responsibility/action (53% of responding teachers), energy (47%), impacts of human activity on the environment (47%), wastes/pollution/disposal issues (42%), and environmental issues and concepts (37%). Within the ethics/responsibility/action theme, common responses revolved around individual decision-making as it related to the green design, production (e.g., building green), consumption, recycling of products and structures, and one's carbon footprint.

The most elaborate expressions occurred within the energy theme. Teachers indicated that they compared alternative and traditional sources of energy, addressed the impacts of extracting and converting energy to produce electricity, and focused students upon energy efficiency. Within the environmental issues and systems category, most descriptions were undeveloped with only general references to *ecosystems* and *ecology*. Greenhouse gases/global warming ($f = 4$ examples) and ground water ($f = 3$) issues were the most frequently occurring topics. Only single references were made to such important environmental issues as *deforestation*, *acidification*, and *over-population*; no explicit references were made to *interdependence of systems*, *food chains*, or *bioaccumulation*.

Nine items asked teachers to indicate how frequently teachers required students to address sustainability concepts when designing or assessing products. Response items were on a 4-point scale ranging from Always (+3) to Never (+0). As indicated in Table 3, the most frequently emphasized concept was *economic value* (*Mdn* = 2.0, Range = 3.0). The least emphasized concepts were *toxicity* (*Mdn* = 1.0, Range = 3.0) and *embedded energy* (*Mdn* = 1.0, Range = 3.0), with 37% of teachers indicating that they never required their students to address these concepts.

Table 3. Pretest: Frequency that Teachers Require Students to Address Sustainability Concepts

When students design or assess a product or system, how often do you require them to consider the following sustainability concepts?	Frequency[1] N=19 Always *f* (%)	Often *f* (%)	Occasion-ally *f* (%)	Never *f* (%)	Median[2]
Energy Efficiency	0 (0)	9 (47)	5 (26)	5 (26)	1.3 (2.0)
Reusability	2 (11)	8 (42)	6 (32)	3 (16)	1.5 (3.0)
Local Availability	2 (11)	5 (26)	7 (37)	5 (26)	1.2 (3.0)
Renewability	1 (5)	7 (37)	6 (32)	5 (26)	1.2 (3.0)
Biodegradability	2 (11)	3 (16)	8 (42)	6 (32)	0.9 (3.0)
Toxicity	1 (5)	4 (21)	7 (37)	7 (37)	0.9 (3.0)
Value ($)	5 (26)	6 (32)	6 (32)	2 (11)	1.8 (3.0)
Recyclability	1 (5)	7 (37)	8 (42)	3 (16)	1.3 (3.0)
Embedded Energy	1 (5)	4 (21)	7 (37)	7 (37)	0.8 (3.0)

[1] Responses ranged from “Always (+3), to Never (0)”.
[2] Calculated from grouped data.

Several items on the posttest attempted to gauge the impact of EnviroTech on teacher’s commitment to addressing sustainability concepts and principles in the future. As indicated in Table 4, the likelihood that teachers will require students to address energy efficiency, reusability, biodegradability, and toxicity when assessing technology (*Mdn* = 1.6, Range = 1) and designing products and systems (*Mdn* = 1.6, Range = 2) is toward extremely likely and suggests an intent to integrate these concepts into the technology curriculum.

Table 4. Post Test: Likelihood of Addressing Sustainability Concepts and Principles

Thinking toward the future, how likely are you to:	Likelihood Responses[1] Extremely Likely *f* (%)	Likely *f* (%)	Undecided *f* (%)	Unlikely *f* (%)	Extremely Unlikely *f* (%)	Median[2] (Range)
Require students to address sustainability principles (e.g., energy efficiency, reusability, biodegradability, and toxicity) when assessing technology?	11 (58)	8 (42)	0	0	0	1.6 (1.0)
Require students to address sustainability principles (e.g., energy efficiency, reusability, biodegradability, and toxicity) when designing products and systems?	11 (58)	7 (37)	0	0	1 (5.3)	1.6 (2.0)
Require students to study hazardous waste management systems?	9 (47)	5 (26)	4 (21)	1 (5)	0	1.3 (3.0)

[1] Responses ranged from "Strongly Agree (+2), Tend to Agree, Don't Know (0), Tend to Disagree, to Strongly Disagree (-2)"; [2]Calculated from grouped data.

Teachers were also asked to state their agreement with statements that probed teachers' judgments about the appropriateness, or value of, specific actions advocated by the project. As shown in Table 5, 68% of teachers strongly agreed that sustainability concepts and principles should be emphasized in the technology education curriculum. Furthermore, 74% of teachers strongly agreed that examining the impact of CFLs and fluorescent lamps on the environment is a meaningful way to meet Standards 5 and 13 of *Standards for Technological Literacy* (ITEA, 2000). To a lesser degree, teachers were in agreement that the CFL activity improved the environment literacy (*Mdn* = 1.35, Range = 4) and technological literacy (*Mdn* = 1.1, Range = 4) of their students.

Table 5. *Post Test: Teacher agreement*

Please indicate how strongly you agree or disagree with the following statements:	Agreement Responses[1] Strongly Agree *f* (%)	Agree *f* (%)	Neutral *f* (%)	Disagree *f* (%)	Strongly Disagree *f* (%)	Median[2] (Range)
Examining the impacts of adopting and disposing of CFLs and fluorescent lamps is a meaningful way for students to meet Standard #5 and 13 of the Standards for Technological Literacy (ITEA, 2000).	14 (73.7)	4 (21.1)	0	0	1 (5.3)	1.7 (4.0)
The technology education curriculum should emphasize sustainability concepts and practices.	13 (68.4)	5 (26.3)	0	0	1 (5.3)	1.7 (4.0)
This activity improved my students' environmental literacy.	8 (42.1)	9 (47.4)	0	0	2 (10.5)	1.4 (4.0)
This activity improved my students' technological literacy	3 (15.8)	14 (73.7)	0	0	2 (10.5)	1.1 (4.0)

[1] Responses ranged from "Strongly Agree (+2), Tend to Agree, Don't Know (0), Tend to Disagree, to Strongly Disagree (-2)"; [2]Calculated from grouped data.

Attitudes and Behaviors about the Impacts of Technology

Teachers were asked to state their level of agreement to nine general statements about relationships among the environment, technology, and society. For example, "The way people dispose of products can negatively impact the health of others." Items were aggregated and statistical comparisons of pre- and post-tests were conducted using the Wilcoxon Signed-Rank test. No significant differences ($Z = -.243$, $p = .808$) were found between pre- and post-tests. Given the self-selected nature of participation in EnviroTech, participants may have been predisposed toward these issues.

In regards to the purchase and disposal of CFLs, however, evidence indicates that the EnviroTech project impacted personal decision-making. On the pretest, only 47% of teachers reported that they dispose of CFLs by taking them to a hazardous waste collection site. On the posttest, 100% of teachers responded that were extremely likely (79%) or likely (21%) to take a spent CFL or fluorescent tube to a hazardous waste collection site. While 95% of teachers indicated that they were likely (32%) or extremely likely (63%) to replace incandescent lamps with CFLs on the posttest.

Teacher Attitudes: Most and Least Effective Elements

The final items on the posttest asked teachers to identify the most and least effective elements of the EnviroTech project and the webinar format. According to frequency of teacher responses, the most effective elements for improving professional skills were: an appreciation for the information presented in webinars (f = 7), working and sharing with other teachers (f = 5), the technology assessment methods, and information about CFLs and mercury (f = 4). For instance, one teacher noted it was the “knowledge gained through webinars regarding Mercury, but also what students found on-line as they answered their own questions.” When asked about the least effective element, the only reoccurring comment related to the difficulty of some topics (f = 2), such as forecasting, force field analysis, and the mercury deposition cycle. One teacher stated, “Not sure that the forecasting, at least as demonstrated, would be something I could get students to do, I struggled to keep my attention focused, and I am sure the students would have more trouble than I.”

In regards to the distributed webinar format, teachers overwhelmingly appreciated the ability to participate in a discussion with people from across the U.S. (f = 8), noted the convenience of “anytime-anyplace” access (f = 5), and the recordings of webinars (f = 3). Comments regarding ineffective elements of the webinar included technical difficulties regarding the audio elements of the conferencing system (f = 9). When asked “how likely are you to enroll in another professional development course which uses a webinar format,” all teachers responded in the affirmative with 79% of teachers indicating that they were extremely likely to do so.

Conclusion

Several *Standards for Technological Literacy* (ITEA, 2000) share common elements with environmental education guidelines (NAAEE, 2010) including the standards/guidelines that speak to examining the environmental impacts of technologies and technological systems and to developing inquiry and analysis skills. However, technology teachers may be ill-prepared, lacking the pre-requisite knowledge and skills they need to integrate environmental concepts and processes into their curriculum and teach technology assessment skills. The EnviroTech project—with its use of distributed webinars, semester-long engagement, and local implementation of guided inquiry projects—demonstrated a viable model for addressing these professional development needs. EnviroTech focused teachers and their students upon a single contemporary consumer decision (adoption of CFL vs. incandescent lamps) and then provided the information, resources, and examples they would need to help their students assess the impacts this decision might have upon the environment and human health.

Prior to starting the project, participating technology teachers reported narrow examples of environmental concepts and teaching strategies used to help students learn how to assess the impacts of technology on the environment. As evidenced by teacher portfolios and pre-/post-assessments, teachers expanded their understanding of environmental processes—especially the mercury deposition cycle and bioaccumulation—and sources of human exposure to mercury, and expanded their repertoire of instructional strategies to include experimentation, calculations of energy efficiency, and comparing lamps and sources of mercury using graphs. Teachers reported strong commitments to implement a broader range of instructional strategies (e.g., life cycle analysis and forecasting) and strong intentions to integrate sustainability principles (e.g., energy efficiency, recyclability, toxicity, and biodegradability) into their student's assessment and engineering tasks in the future.

Although these teachers strongly agreed that examining the impact of CFLs and fluorescent lamps on the environment is a meaningful context by which to meet Standards 5 and 13 of STL (ITEA, 2000), it is clear that achieving these standards will require much more focused efforts from curriculum developers, researchers, teacher educators, and others who deliver professional development experiences to technology teachers. Assessing technology requires sophisticated understandings of the environment and technology, as well as the inquiry and mathematical skills that enable learners to analyze and predict potential impacts. We need to test promising pedagogies that weave together multidisciplinary knowledge sets and engage students in authentic assessment tasks. Life cycle analysis, forecasting, and data-driven decision-making—such as force field analysis—are powerful tools for assessing the impact of technology on the environment. We still have much to learn about how and when to use these analysis tools in a technology classroom. An examination of lighting choices, coal-fired electricity generation, and the mercury deposition cycle is but one example of how we could simultaneously enhance the environmental and technological literacy of teachers and their students. But the important outcome is that we develop both the skills and will to make environmentally-sound, better-informed decisions about the technology we adopt, design, use, and discard.

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A Study of Mathematics Infusion in Middle School Technology Education Classes

M. David Burghardt, Deborah Hecht, Maria Russo,
James Lauckhardt, and Michael Hacker

The transition into the twenty-first century has led to a greater emphasis placed on student proficiencies in Science, Technology, Engineering, and Mathematics (STEM), with a particular focus on how these skills will help students thrive in the technological world and society. Most jobs require some level of mathematical proficiency, and mathematics skills are crucial for successful integration and independence in the home and community (Patton, Cronin, Bassett, & Koppel, 1997). Yet, mathematical achievement in the United States has been below the level attained by students in other countries, with American students becoming notably behind once they reach late middle school (U.S. Department of Education, 2008). To address these weaknesses, educators have developed various methods to increase student's STEM content knowledge. These include, but are not limited to, furthering teacher's professional development (PD) requirements, varying curriculum, and adding additional STEM classroom time.

One way to increase student competency in mathematics is to make connections between the STEM areas to assist in the student's broader understanding of similar concepts and ideas. Connected curriculum is not a new pedagogical approach and has been recognized as an important teaching tool to assist student learning for many years (National Research Council, 1996). The National Council of Teachers of Mathematics (NCTM) endorsed the use of mathematics as a connector, as it recommended connecting mathematics to situations from science, social science, and commerce as a way for students to increase their mathematical competence (National Council of Teachers of Mathematics, 2002). Thus, a useful way to apply connected curriculum is to use mathematics as the thread that links Science, Technology, and Engineering curriculum together.

Unfortunately, there has been a paucity of research studying the effects of connected STEM curriculum, especially in regards to connecting mathematics to engineering/technology education (ETE). Preliminary research by Atkins and Burghardt (2006) investigated connected mathematics and ETE curriculum through the design and construction of a food dehydrator. When using

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mathematical skills to develop this project, it was found that all students benefited from the experience. More specifically, students in the bottom two quartiles showed the greatest improvement in mathematical reasoning and achievement.

As part of the general effort to promote research in connecting the STEM areas, a national invitational STEM Symposium (STEM Symposium, 2009) was held in order to develop recommendations and a research agenda for interconnected STEM teaching and learning. During the STEM Symposium 45, prominent STEM researchers, assessment specialists, school administrators, and STEM teachers met to discuss the importance of creating connections between these fields in the classroom. There was agreement across these groups of professionals that these connections will prove to be powerful in helping students learn Mathematical and ETE concepts and achieve a higher level of proficiency in these areas.

Bedroom Design Curriculum

The present study was part of the *Mathematics, Science, and Technology Project* (MSTP), a National Science Foundation (NSF) funded Mathematics and Science Partnership Project (MSTP, 2003), conducted by Hofstra University's Center for Technological Literacy (CTL). MSTP's goal was to improve mathematics teaching and learning in low performing middle schools in New York State. One way to accomplish this goal was through enhancing ETE curriculum with additional mathematical content, as well as providing teachers with PD in mathematics pedagogical and content knowledge to deliver this curriculum. In both the MSTP project and the current research, the term *mathematics infusion* was introduced as an approach to make the connections between mathematics and technology. Through infusion, mathematics is introduced in ETE curriculum at critical points, so it naturally fits with the material taught and makes connections between the disciplines.

The curriculum that was selected for mathematics infusion in the present study was entitled *Bedroom Design.* This curriculum was developed and enhanced by MSTP's principal investigators, consultants, and curriculum experts over three years, including two field test trials to ensure its feasibility to be taught in middle school classrooms. The Bedroom Design activity is a 20-day middle school ETE curriculum, which engages students in the planning, designing, and physical modeling of a "bedroom" that must meet specific cost and building requirements (e.g., the window area must be at least 20% of the floor area, the minimum room size is 120 square feet, the minimum closet size is 8 square feet, etc). Bedroom Design was considered a *hybrid* instructional model. It is hybrid because students first virtually model a bedroom through Google SketchUp (GSU), a 3D modeling program available at no cost from Google, then students build their virtual model using physical construction materials. Figure 1 provides a student example of the GSU virtual and physical model.

Figure 1
Bedroom Design Unit Students used Google SketchUp to design their bedroom (top) and then built as a physical model (bottom)

According to Robinson (1994), in order for connected instruction to be successful, the lesson should support some aspect of instruction in the core subject area and should be constructed in a manner that encourages students to integrate and use new knowledge and skills from several areas of competence. The Bedroom Design curriculum accomplished this, as the curriculum is implemented using informed design, which is a validated design pedagogy developed through NSF projects conducted by the CTL (Burghardt & Hacker, 2003). Informed design encourages students to increase their content knowledge before they suggest a solution to a problem, in order to be informed by prior knowledge, instead of trial and error (Burdhardt & Hacker, 2004). In an informed design activity, students expand their STEM knowledge and skill base by completing a series of short, focused tasks called *Knowledge and Skill*

Builders (KSBs). The mathematical KSBs were the crucial Bedroom Design tasks that infused grade-related mathematics, enabling technology educators to reinforce mathematics within the technological context. There were a total of seven KSBs in the Bedroom Design curriculum. These included: geometric shapes, factoring, percentages, mathematics of scale, mathematical nets, aesthetics, and spreadsheets/pricing information.

Purpose of the Present Study

The present study examined the impact of introducing a mathematics infused ETE curriculum on students' mathematics content knowledge and attitudes toward mathematics. The purpose of the present study was to: (a) compare the effects of a mathematics infused ETE curriculum and a control curriculum on student mathematical content knowledge, (b) compare the effects of a mathematics infused ETE curriculum and a control curriculum on student attitudes toward mathematics, and (c) examine if treatment conditions were equally effective for students' whose mathematical levels were particularly below the average. It was hypothesized that students, even those below average, who participate in mathematics infused ETE curriculum will increase their mathematical conceptual knowledge and attitudes toward mathematics, and will improve these mathematics skills at a greater rate than students who receive the control curriculum.

Method

Participants

Student participants were from 8th grade ETE classrooms in 13 middle schools in New York State (NYS). There were 15 teachers who taught the mathematics infusion lessons to a total of 598 students. The teachers had an average of 14 years of teaching experience, with a range from two to 33 years. Twelve teachers currently held master's of education or a master's of science in a related technological field and all were certified to teach Technology Education in NYS. There were 14 teachers who taught the control curriculum to 455 students. All of these teachers were certified to teach Technology; however, their years of experience and education were unknown, but expected to be comparable to infusion teachers.

Procedure

The study used a pre/post design to examine student change in mathematical content knowledge and attitudes toward mathematics following participation in the mathematics infusion curriculum. Data were collected from students in both the infusion and control classes. The total time to teach the Bedroom Design curriculum was 20 days (approximately 45 minute class period each day). However, due to various scheduling and/or other reasons, some ETE teachers went over the predetermined 20 days, ranging from 20 to 28 with an average of 24 days. As part of the design, each technology infusion teacher was paired with a control teacher (typically another technology teacher from the same middle school) who did not teach Bedroom Design, but instead taught the *business as usual* curriculum for that school.

*Bedroom Design mathematics infusion curriculum***.** All infusion teachers met for ten days of collaborative PD during the summer prior to implementing the Bedroom Design curriculum. During this time, mathematics, technology, and engineering content knowledge and pedagogical experts helped guide, mentor, and provide training for the middle school teachers. The technology teachers worked together with these experts to enhance each day of the curriculum with additional mathematical content. This allowed for a final curriculum, as was described earlier, that all technology teachers were familiar with and knowledgeable in, both conceptually and pedagogically.

Control business as usual curriculum. The control classes were taught by an 8th grade technology teacher and exposed to their regular 8th grade technology curriculum, which included six topics (systems thinking, models, magnitude and scale, equilibrium and stability, patterns of change, and optimization) aligned with the NYS curriculum standards. Lessons varied from school to school, as the majority of ETE teachers had freedom to choose what specific areas to cover. However, no control teacher formally incorporated any of the seven KSBs into his or her lessons.

Measures. Both infusion and control students completed two assessments (mathematical content knowledge and attitudinal) prior to and after completing the Bedroom Design curriculum for infusion students and the control curriculum for control students. Further, a teacher feedback survey was administered weekly to all infusion teachers.

Mathematical content assessment. This measure included seven multiple-choice and ten open-ended questions (one question included both open-ended and multiple-choice components). Questions were either adapted from the NYS eighth grade mathematical assessment or developed by an expert mathematics consultant to the project. These items involved mathematical concepts that were included in the technology Bedroom Design curriculum surrounding six of the seven KSBs (excluding the KSB that dealt with aesthetics). Table 1 depicts the specific question and content area.

Table 1
Question number matched to content of mathematics content knowledge assessment.

Question	Type of Question	Content
1	Open-Ended	Geometric Shapes
2	Open-Ended	Mathematics of Scale / Factoring
3	Multiple-choice and Open-Ended	Percentages
4	Open-Ended	Pricing Information
5	Multiple-choice	Pricing Information
6	Open-Ended	Geometric Shapes
7	Open-Ended	Geometric Shapes
8	Multiple-choice	Mathematics of Scale

9	Open-Ended	Pricing Information / Percentage
10	Open-Ended	Geometric Shapes / Pricing Information
11	Multiple-choice	Geometric Shapes
12	Open-Ended	Pricing Information / Percentage
13	Multiple-choice	Mathematical Nets
14	Open-Ended	Mathematics of Scale / Percentage
15	Open-Ended	Pricing Information /Factoring
16	Multiple-choice	Mathematics of Scale / Percentage

The content analysis questions were graded by 5 mathematics teachers with twenty-plus years of experience. All questions were scored using a rubric modeled after the NYS middle school mathematics assessment rubrics. Teachers were trained in the use of this rubric and scoring did not begin until raters consistently scored practice questions the same. The multiple-choice questions were scored as either 0 (incorrect) or 1 (correct). The open-ended questions were scored using a three-point rubric ranging from 0 to 2 (0 representing no evidence of understanding, 2 representing full understanding), with the possibility of getting half credit (e.g., .5 or 1.5) for partial understanding.

Mathematical attitudinal assessment. The mathematical altitudinal assessment was developed during prior work by MSTP to assess the major dimensions of mathematics infusion into ETE curriculum. This assessment was previously validated during a pilot study in which experts in technology education developed and micro-tested items with 8^{th} grade students from similar demographics as the current study. Factor analysis revealed that items on the attitude assessment all loaded at levels of .500 or above on three factors: relevance of mathematics, interest in mathematics and understanding of mathematics. Reliability analyses revealed an alpha coefficient of .877 or higher for each of the factors as well. Due to the high factor loadings and reliability analysis results, the same items were used in the current study to assess student attitudes. The assessment consists of two different groups of statements. The first fourteen likert-type statements asked about student feelings toward mathematics in ETE classes. The second nine statements asked students about their confidence in doing a variety of mathematics related tasks that are needed in Bedroom Design (e.g., solving measurement problems).

Teacher feedback survey. This measure was administered in the form of a weekly online survey to all infusion teachers who participated in the study. The purpose of this measure was to keep track of the mathematical KSBs teachers implemented, as well as their progress, thoughts, and concerns when teaching the Bedroom Design unit.

Interrater reliability. Interrater reliability was assessed for the mathematical content assessment for both pre- and post-assessments. Thirty percent of the assessments were randomly selected for rating a second time in order to calculate a rate of agreement across scorers. Two different scorers independently rated the ten open-ended mathematics questions, using the same mathematical rubric.

Results

Prior to data analysis of the mathematics content assessments, students who did not complete at least half of the pretest and half of the posttest were dropped from the analyses. Based on these criteria, the final sample included 811 students for the content assessment (484 infusion and 327 control students). For the students who were missing responses on each subscale (multiple-choice and open-ended), zeros were substituted for missing answers, assuming students skipped these questions due to an inability to answer. Analyses were conducted at both the individual item level and aggregate summed score level.

Mathematical Content Analysis

Individual question level change. At the individual question level, increases in student scores were seen for both the multiple-choice and open-ended questions in the infusion group. Infusion students scored higher on four of the seven multiple-choice questions: Question 3 = 5.4% increase, Question 11 = 12.0% increase, Question 13 = 26.6% increase, and Question 16 = 5.6% increase (content was percentages, geometric shapes, mathematical nets, and mathematics of scale/percentages). Additionally, infusion students scored higher on four of the ten open-ended questions: Question 6 = .26 M increase, Question 12 = .16 M increase, Question 14 = .10 M increase, and Question 15 = .36 M increase (content was geometric shapes, pricing information/percentages, pricing information/factoring, and mathematics of scale/percentages). Control students increased their scores from pretest to posttest on only three multiple-choice questions (Question 11 = 11.6% increase, Question 13 = 12.9% increase, and Question 16 = 9.8% increase) and two open-ended questions (Question 6 = .18 M increase and Question 15 = .37 M increase).

An independent-samples t-test revealed significant differences between the infusion and control group on two multiple-choice questions, Question 5 ($t(809) = 2.00$, $p < .05$) on pricing information and Question 11 ($t(809) = 2.97$, $p < .01$) on geometric shapes, where infusion students scored higher, and one multiple-choice question, Question 8 ($t(809) = 1.99$, $p < .05$) on mathematics of scale, where control students scored higher. However, on seven of the open-ended questions, infusion students scored significantly higher than control students at posttest. This included the majority of KSB topics: Question 1 ($t(809) = 3.25$, $p < .01$), Question 4 ($t(809) = 3.25$, $p < .01$), Question 9 ($t(809) = 5.18$, $p < .01$), Question 10 ($t(809) = 5.68$, $p < .01$), Question 12 ($t(809) = 7.41$, $p < .01$), Question 14 ($t(809) = 4.38$, $p < .01$), Question 16 ($t(809) = 3.06$, $p < .01$). Moreover, there were no post-questions where control student means exceeded those of infusion students. Results are show in Table 2.

Table 2
Change in Multiple-choice Questions, Open-Ended Questions, and Total Score

Multiple-choice	Infusion Classes (Matched Pre/Post Data)			Control Classes (Matched Pre/Post Data)			Infusion v. Control (Post Data)		
Question Number	% Correct Pre	% Correct Post	Increase	% Correct Pre	% Correct Post	Increase	t	df	Mean Difference
2	62.2%	56.2%	-6.0%*	62.7%	48.9%	-13.8%**	1.44	809	0.142
3	61.8%	67.2%	5.4%*	58.7%	59.9%	1.2%	0.39	809	0.023
5	39.7%	40.3%	0.6%	32.7%	31.2%	-1.5%	2.00	809	0.171*
8	67.6%	62.8%	-4.8%*	58.1%	50.2%	-7.9%**	-1.99	809	-0.164*
11	72.7%	84.7%	12.0%**	63.6%	75.2%	11.6%**	2.97	809	0.163**
13	39.9%	66.5%	26.6%**	33.3%	46.2%	12.9%**	-1.06	809	-0.050
16	38.2%	43.8%	5.6%*	22.6%	32.4%	9.8%**	-0.06	809	-0.004
Total Score (out of 100%)	54.57%	60.21%	5.64%**	47.40%	49.15%	1.75	6.28	809	11.07**

Table 2 continued on next page

Open-Ended	Infusion Classes (Matched Pre/Post Data)			Control Classes (Matched Pre/Post Data)			Infusion v. Control (Post Data)		
Question Number	Mean Pre	Mean Post	Mean Difference	Mean Pre	Mean Post	Mean Differenc	t	df	Mean Difference
1	1.27	1.23	-.04	1.12	1.07	-.05	3.25	809	.16**
3	1.04	1.12	.08	.94	1.03	.09	1.48	809	.09
4	.23	.25	.02	.22	.19	-.03	2.98	809	.06**
6	.78	1.04	.26**	.67	.85	.18**	2.74	809	.19
7	1.19	1.12	-.07	1.07	.97	-.10	2.05	809	.15
9	.91	.86	-.05	.85	.55	-.30**	5.18	809	.31**
10	.40	.44	.04	.19	.15	-.04	5.68	809	.29**
12	.42	.58	.16**	.19	.22	.03	7.41	809	.36**
14	.37	.47	.10**	.21	.28	.07	4.38	809	.19**
15	.53	.89	.36**	.31	.68	.37**	3.06	809	.21**
Total Score (out of 100%)	35.66	40.00	4.34**	29.03	30.00	.07	6.05	809	10.00**

Note: *p < .05, **p < .01

Multiple-choice and open-ended composite score change. Composite scores were computed for the multiple-choice questions and the open-ended questions separately by dividing the sum of a student's responses to each type of question by the total number possible correct responses for that type of question and then multiplying by 100. Thus, each composite score represented a percentage correct out of 100%. Infusion students' composite scores were higher and statistically significant on the posttest when compared to their pretest scores for both the multiple-choice (% increase = 5.64) and open-ended questions (%increase = 4.34). There were no significant differences between pre- and posttest composite scores for control group students.

An independent-samples t-test was used to test for statistically significant differences between infusion and control students on their post-scores. Results showed that composite scores for infusion students were statistically significantly higher for both the multiple-choice (t (809) = 6.28, p < .01) and open-ended questions (t (809) = 6.05, p < .01), when compared to their control group counterparts, even after controlling for initial composite pre-score differences between groups.

Total score change. A mathematics content total score was computed for each student by adding the multiple-choice and open-ended composite score (both of which reached a maximum of 100), dividing by 200, and multiplying by 100 in order to maintain a scale of 0-100. An independent samples t-test revealed no significant differences between pre- and post-scores for control students. As indicated in Table 3, for infusion students, post-scores were a statistically significant amount higher than their pre-scores (% increase = 4.98). When compared with control students, the infusion students scored significantly higher on their post-scores after controlling for pre-score differences (t (809) = 6.72, p < .01).

Table 3
Total Score Changes for Mathematical Content Knowledge Assessment

	Infusion Classes (Matched Pre/Post Data) (n= 484)			Control Classes (Matched Pre/Post Data) (n= 327)			Infusion v. Control (Post Data)		
	Mean Pre	Mean Post	Mean Difference	Mean Pre	Mean Post	Mean Difference	T	Df	Mean Difference
Total Score	45.12	50.10	4.98**	37.95	39.57	1.62	6.72	809	10.53**

Note: *p < .05, **p < .01

Content-level change. An independent samples t-test was conducted to assess whether significant differences existed between the infusion and control group students at posttest for their content knowledge based on the knowledge and skill builders (KSB) described above. Sum scores were created using the items that fell into each KSB category. Students in the infusion group scored significantly higher at posttest in the areas of pricing information (M = 6.08, *SD = 2.91*), percentages (M = 4.98, *SD = 1.81*), factoring (M = 3.28, *SD = 2.03*), and geometric shapes (M = 4.23, *SD = 2.50*) than their control group counterparts (pricing: M = 4.71, *SD = 2.38*, percent: M = 4.56, *SD = 1.89*, factoring: M = 2.71, *SD = 1.91*, and geometric shapes: M = 3.42, *SD = 2.16*).

Quartiles. Students were divided into quartiles based upon their pretest assessment performance. Thus, each student was assigned to either the first, second, third, or fourth quartile based upon the pre-score, in essence breaking the sample into four smaller subsamples. The average pre-score and post-score for students in each quartile was then computed. As is displayed in Table 4, the average post-scores were higher than the pre-scores in three out of the four quartiles (Quartile 1 = +12.01, Quartile 2 = +6.96, and Quartile 3 = +3.9). Moreover, the performance change was most dramatic for students who scored in the first and second quartiles, indicating that those students who were lower performing in mathematics improved the greatest.

Table 4
Average Pre- and Post-Scores for Students in Each Quartile Mathematics Content Assessment

	Quartile			
	1	2	3	4
Pre-Score	17.51	36.01	52.14	72.83
Post-Score	29.52	42.97	56.04	71.77
Difference	+ 12.01	+ 6.96	+ 3.9	- 1.06

Mathematical Attitude Analysis

In order to account for missing cases in the attitude dataset, variable means were substituted for any student who had one or two missing cases (84 and 57 students respectively). Students with three or more missing cases were excluded from the analysis. As a result, the total sample size was reduced to 1004 cases (561 infusion and 443 control students).

Mathematics attitudes factor analysis. A principal components factor analysis of the pretest scores was conducted in the 14 likert-type attitude questions. Pretests were collected before students had any exposure to Bedroom Design; therefore, it was decided to use responses from both the infusion and control students, thereby maximizing the number of data points in the analysis. Factor loadings greater than .300 following a varimax rotation were examined in order to interpret the factors. The analysis found a three-factor solution, which accounted for 42.45% of the common factor variance. One item failed to load on any of the three factors and was excluded from the interpretation. The three factors addressed were: (1) perceived level of importance of mathematics in technology, (2) interest in mathematics, and (3) relevance of mathematics. Alpha reliability coefficients, as displayed in Table 5, revealed perceived level of importance of mathematics in technology (Reliability = .80); interest in mathematics (Reliability = .68); and relevance of Mathematics (Reliability = .59) as statistically significant factors.

Mathematics confidence factor analysis. The nine attitude statements about students' confidence in completing a variety of math tasks were examined separately. Again, it was decided to use responses from both the infusion and control students, thereby maximizing the number of data points in this analysis. A principal axis factor analysis revealed that the data were best represented by a single factor accounting for 42.14% of the common factor variance. The single Math Confidence scale had an alpha reliability of .855. Table 5 shows the factor and each questions loading.

Table 5
Factor Loadings for the Mathematical Attitudinal Data

Statements	Factor Ladings following Varimax rotation		
Factor One: Math is Important for Technology			
Statements	*Alpha Reliability = .802*		
Math and Technology are closely connected.	0.688	0.154	-0.195
Being able to do math makes learning Technology easier.	0.680	0.204	-0.250
Math is important for constructing tasks in Technology class.	0.647	0.166	-0.195
I expect to use a lot of math in this class.	0.643	0.253	-0.073
My Technology teacher must understand a lot of math.	0.545	0.099	-0.017
Doing well in Technology class is important to me.	0.373	0.361	-0.011
Factor Two: Interest in Math			
Statements	*Alpha Reliability = .676*		
I like to do Technology projects that require math.	0.381	0.648	-0.04
Math is interesting.	0.157	0.592	-0.334
I am able to solve complex math problems.	0.160	0.591	-0.223
I find math confusing.	0.093	0.515	0.479
I am interested in a math or technology related career.	0.254	0.503	0.002
Factor Three: Relevance of Math			
Statements	*Alpha Reliability = .589*		
I can do well in Technology class without understanding the math. (Recode)	-0.298	-0.013	0.605
The math I learn in school has no relevance to my life. (Recode)	-0.053	-0.088	0.516
I do not understand why I need to study math.	-0.112	-0.144	0.484

Table 5 continued on next page

Math Confidence Factor	
Statements	*Alpha Reliability = .855*
Calculate area and perimeter.	0.736
Measure and calculate with standard units (e.g., inch, foot, and yard).	0.721
Calculate volume, mass or density.	0.719
Solve problems that involve money.	0.682
Analyze graphs.	0.672
Solve ratio problems.	0.668
Use graphs to show growth.	0.634
Work with proportions.	0.602
Use computers to draw figures.	0.295

Mathematical attitudes. Scale scores were computed by summing student responses to questions that fell within each scale and dividing by the total number of items, thus placing the scale scores on the same scale as the original statements, ranging from 1 (not at all true) to 5 (very true). Means were then examined for the infusion students and control students. Four analyses of covariance were conducted to explore attitude differences between infusion and control students after controlling for their initial (pre-score) attitudes. Results indicated that infusion students felt mathematics was more important in technology $F(1,807) = 4.183$, $p < .05$; and found mathematics more interesting in technology $F(1,782) = 7.261$, $p < .01$ than control students. Statistically significant differences were not found on the other scales.

Paired Samples t-tests were also used to compare pre- and posttest composite scores of infusion students. When the three factor scales were combined into a composite scale (Mathematics attitude composite scale) a negative significant difference was found between the infusion pre- ($M = 3.64$, $SD = .91$) and post- ($M = 3.51$, $SD = .92$) scores at the $p < .05$ level, indicating students had a slightly more negative attitude toward mathematics at posttest than at pretest. Further, independent Samples t-tests found statistically significant differences between the infusion ($M = 3.82$) and control ($M = 3.95$) groups on the Mathematics Relevance composite. In essence, infusion study participants felt that mathematics was less relevant to their lives than control students. No other composite scores were significantly different between infusion and control participants.

Experience with computer programs. Correlation analysis revealed statistically significant correlations between level of overall experience with the computer programs (Google SketchUp, Microsoft Excel, etc.) and Interest in Mathematics ($r = .15$), Importance of Mathematics in Technology ($r = .13$), and Confidence in Mathematics ($r = .22$). In essence, students who had more experience with the computer programs mentioned above were more likely to feel confident in their mathematics skills, to see the importance of mathematics in technology, and to be interested in mathematics.

Predictors of Posttest Mathematics Content Score

Regression analysis revealed that after controlling for participant pretest content knowledge (predicting 57% of the variance in posttest score), confidence in mathematics skills was the only significant attitude item that predicted posttest content knowledge (predicting 60% of the variance of their posttest score when combined with the pretest content knowledge predictor).

Interrater Reliability

As mentioned previously, 30% of the assessments were randomly chosen and an interrater reliability was calculated for the open-ended questions on the content assessment. A high level of consistency was found between the two ratings for these questions ($r = .877$). In addition, there was an average consistency rate of 85.09% between rater 1 and rater 2 across all 10 questions. For individual questions, this rate ranged from 72.50% to 94.20%.

Teacher Feedback

Based upon debriefing focus groups and weekly online surveys, it was found that teachers reported the experience to be very valuable for both their teaching practices and for their students. The majority of teachers (95%) said they would definitely implement the unit again. Some teachers noted that their students did complain initially about the amount of mathematics in the lessons; however, the further students progressed in the unit the more their complaints subsided. The teachers reported that students were able to use Google Sketch-Up with very little difficulty; it took about one-class period for instruction and then they could create rooms, furniture, and furnishings using the software.

Discussion

The purpose of the present study was to identify and compare the effectiveness of middle school student exposure to an ETE curriculum that infuses mathematics to students who were not exposed to the mathematics infused curriculum. Pre/post differences in both student mathematical content and attitudinal data were examined. In terms of mathematical content data, infusion students increased their scores from pre- to posttest for some individual multiple-choice questions, the composite multiple-choice score, all open-ended items, and for the total score assessment. When compared to control students, infusion students scored significantly higher on two multiple-choice questions, all ten open-ended questions, the multiple-choice composite, the open-ended composite, and the entire assessment. This indicates that students in the infusion group showed significant increases in content scores after being exposed to the mathematics infused curriculum. These results are encouraging, indicating that the infusion group students learned content that increased their mathematics knowledge, above and beyond increases that would exist by virtue of being in a typical technology class.

Interestingly, specific content areas (i.e. pricing information, factoring, percentages, and geometric shapes) showed greater improvements in infusion student knowledge. This shows that it is possible for students to learn specific mathematical content knowledge in the content in an ETE classroom environment. It is hopeful that infusion students showed significant gains in many of the targeted content areas specifically due to their instruction in the Bedroom Design curriculum. However, not all mathematical content areas that were infused showed a significant improvement in infusion students versus control students (e.g., mathematical nets and mathematics of scale). It could be the case that teachers focused their time on certain content areas as opposed to others. An additional explanation for the disparity in scores could be that even though ETE teachers were administered rigorous PD, these concepts are not typically taught in a middle school technology classroom and teachers may have struggled with teaching the content.

Analysis of the quartile data showed the greatest improvement in students who initially scored in the lowest quartiles. Since the intervention was targeted toward students in low-performing schools, this result was not surprising. Students who started out with lower scores had a greater chance for improvement than students who started out with higher scores. Therefore, participation in the Bedroom Design unit had a positive impact on students, in that they were better able to apply mathematical concepts to their work in technology class. These findings should not only encourage more research into the impact of infusing mathematics into STEM courses, but should also be shared with practitioners in order to promote the effectiveness of this curricular approach. Mathematics achievement as a whole in the United States is imperative to address, and studies and programs like the ones mentioned in this article are a promising first step towards improving scores.

In terms of attitude changes, infusion students felt that mathematics was more important and interesting in technology than control students, seemingly due to their increased knowledge of the utility of mathematics in design challenges. However, infusion students reported a decreased interested in mathematics and relevance at posttest. This could be a result of over-exposure to the difficult mathematics concepts that were presented as part of the Bedroom Design unit. In addition, students were exposed to the curriculum over the course of a month, which may not have been enough time to absorb the value of the mathematics that they were being exposed to. The curriculum is math intensive and may seem overwhelming to students at first (reflected in their posttest scores), but a follow-up survey of mathematics attitudes toward the end of the year, when students would be given the chance to use what they have learned, may have yielded different results. Finally, the attitudes assessment asked students to reflect on their opinion of mathematics overall, and was not phrased for students to reflect on their opinion toward mathematics as it was contextualized within ETE. The rephrasing of some of these questions may have resulted in different patterns of response.

Limitations and Future Directions

There are several noteworthy limitations of this study. First, it was difficult to monitor the material taught within the control classrooms. These teachers were instructed to implement their own technology curriculum, but little was done to examine the curriculum itself, the level of mathematics that was introduced, and the pedagogy used. It would have been beneficial for control teachers to keep a running record of this information in order to gain insight into these technology classrooms. Furthermore, teacher quality (both infusion and control teachers) may have had an impact on student engagement and learning of the mathematics. Future research should monitor, account for, and examine aspects of teacher quality to a higher degree than the current study addressed.

Additionally, randomization of condition (i.e. randomizing which teachers taught infusion and which taught control classes) would be the next critical step to validate the results. In the current study, control groups were created; however, they were not assigned randomly. It is possible that the teachers who participated in infusion classes were more interested in the content, more invested in student learning, or were open to the idea of being part of a two week PD initiative. All together, these factors might have lead to the self-selection of a higher-quality infusion teacher participant versus a control teacher participant. To control for this type of influence, it is important to obtain a sample of teachers first who all share similar characteristics and randomize each teacher to a specific condition.

It is necessary that further research be conducted involving mathematics infusion in a number of different facets. First, new mathematics infused in ETE materials must be developed for both the middle grades and all grade levels. These materials should be based on research that has identified the mathematics topics that are most relevant at each grade level and where mathematics can be appropriately connected and infused. Secondly, adequate PD needs to be provided for teachers to prepare them for mathematics infusion instruction. Research should focus on what type of PD is most successful for mathematics infusion in STE, and must determine if PD should be stand-alone workshops, collaborative STEM learning communities, additional mathematics content and pedagogy training, or perhaps a combination of all three. Lastly, additional research must document if mathematics infusion will improve student scores on existing assessments, or if new assessments may need to be developed. The new assessments must allow for the unique contributions of mathematics infusion that current assessments may not account for. It might prove valuable to target assessments on: primary discipline knowledge (ETE), infused discipline knowledge (mathematics), unique student outcomes (e.g., creating designs, seeing connections within disciplines, problem solving), improvement in student attitudes and self efficacy, student engagement in STEM, and the likelihood of students pursuing further studies and/or careers in STEM related fields.

The implications of this mathematics infused approach are great. Not only is it critical to find ways to enhance mathematical understanding and competencies among students, but it is also important that students to be proficient in the mathematical concepts that are required to master concepts and real-world problems.

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Graduate Research in Technology and Engineering Education: 2000-2009

W. Tad Foster

Introduction

In the 1990s, significant attention was given to the status of research in the Technology and Engineering Education (TEE) field and the direction for future research (Foster, 1992, 1996, 1999; Wicklein, 1993; Zuga, 1994, 1999, 2001; and Lewis, 1999). This research and dialogue resulted in numerous recommendations for future research and practice. Although each effort was unique, it is possible to assert that there existed general agreement that research was important to the field's future and was one of the primary means by which the field would continue to develop and mature. It was also clear, that collectively this body of literature supported the notion that more research was needed that focused on key questions that provide a theoretical foundation for the field. A brief summary of this literature follows.

Relevant Literature

With funding from the Council on Technology Teacher Education, Foster (1992) completed an analysis of 503 doctoral dissertations and masters theses completed from 1985 to 1990. Using content analysis techniques, he reviewed the title pages and abstracts of these studies (and when necessary, the full manuscript). The analysis revealed an average of 84 dissertations/theses annually (72% at the doctoral level). The majority of the studies employed self-reporting techniques (i.e., the survey method) and were focused on program/project evaluation (19.3%) and instructional methods (10%). Foster noted that one would be justified in concluding that the graduate research reviewed constituted a group of "stand-alone" studies focused on a wide-range of questions. He concluded by calling for a greater focus on "seminal issues facing our fields" and the use of more powerful research designs.

This research led to a study whereby Foster (1996) attempted to identify an agenda for Technology Education researchers. This project was partially sponsored by the Technical Foundation of America (TFA) and was presented at TFA's 1996 Issues Symposium. Before the symposium, Foster surveyed 40 researchers/leaders in the field to rank order 21 topics as to their level of importance for future research. In addition, he presented seven statements that were described as a "set of theories deduced from the literature." He asked the respondents to rate each statement as to whether the statement was, in their opinion, (a) a foundational theory, (b) adequately research, and (c) should be a major concern for future research. Table 1 is a summary of those topics with emphasis on the top ten. Six of the seven "theoretical" statements, included in

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Table 2 were ranked above a 4.0 on a five point scale. The numbers in parentheses following each of the statements in Table 2 represent the mean and standard deviation for two of the three questions: (a) should this statement be considered a foundational theory for the field, and (b) should this statement be a major focus of future research.

Table 1. *Foster's (1996) Top Research Topics for the Technology Education Field in Rank Order.*

		Adequately Researched		**Major Topic for T.E.**	
		X	**S.D.**	**X**	**S.D.**
1.	Integration of educational disciplines (e.g., M/S/T)	2.15	0.87	4.39	0.61
2.	The role of technology education as general education for all students	2.42	1.20	4.27	0.88
3.	Rationale for technology education	2.76	1.35	4.24	1.03
4.	The capability (i.e., effectiveness) of technology education programs to deliver technological literacy	1.91	0.91	4.24	0.83
5.	Nature of technological literacy	2.42	1.20	4.18	1.04
6.	Need for technological literacy	2.73	1.33	4.09	1.07
7.	The nature & effectiveness of applied instructional techniques (i.e., learning by doing)	2.55	1.06	4.03	0.95
8.	Impacts of technology on people and society	2.52	1.09	4.06	0.83
9.	Effectiveness of various instructional techniques	2.82	1.18	4.00	0.94

Others: Definitions (3.36, 1.17; 3.73, 1.31); The relationship between T.E. & other programs (2.39, 1.03; 3.64, 1.03); The nature of learning (2.79; 1.36; 3.52, 1.30); Organizational models for K-16 education (2.52, 1.00; 3.45,1.25); Historical topics (2.85, 0.97; 3.42, 1.00); Change in educational institutions (2.61, 1.17; 3.33, 1.22); Impacts of technology on industry (3.06, 0.97; 3.36, 1.06); Dev. & application of educational technology (2.97, 1.10; 3.36, 1.14); The impact of federal funding on education, in general, and technology education, in particular (2.76, 0.83; 3.27, 1.13); General education issues (3.00, 1.00; 3.12, 1.24); Employment trends and projections (3.33, 0.92; 3.03, 1.05); Technical research (3.06, 1.14; 3.00, 1.30).

Table 2. *Mean and Standard Deviation on the Value of Seven Statements as Elements of Theory for Technology Education*

1. Upon the completion of high school every student should have a "citizens" level of understanding of and ability with technology (i.e., technological literacy as commonly defined). In other words, a basic awareness of and ability with technology is essential for survival and productive citizenship now and in the future (4.58, 0.50; 4.15, 0.91).
2. Technology education is a primary means by which "technological literacy" can be delivered to all students (4.24, 0.97; 4.09, 1.04).
3. Learning by doing in a "real-world" context is the primary means by which most people learn most effectively (4.15,0.91; 3.94, 1.12).
4. Human endeavor provides the best organizer for the content of K-12 technology education. In addition, human endeavor falls into three categories: producing things, communicating information and ideas, and transporting people and things (3.52, 1.20; 3.55, 1.03).
5. Technology is systematic and should be studied as such. To adequately understand technology, students should be exposed to the components and processes of a wide variety of technological systems (4.15, 0.91; 3.73, 1.01).
6. Technological activity produces positive and negative impacts. An understanding of these impacts is a major component of "technological literacy." To properly understand technology, students must be exposed to these impacts and explore solutions for negative impacts of various technologies (4.42, 0.50; 4.15, 0.80).
7. Successful human beings in a post-industrial society must be able to think clearly, creatively, and critically. They must be able to identify and solve problems, and make good decisions. Technology education is a primary means by which students can be taught to think (4.24, 1.12; 4.15, 0.97).

During the symposium, Foster presented the survey data, but used the majority of the time to conduct a "strategic planning" session to address the following questions: What would be ideal for research in the field? What roadblocks were preventing the realization of the ideal? Interestingly, there was general consensus that the major roadblocks were the low status of research (i.e., limited resources, and rewards; and that it was boring and of low perceived value), the nature of the questions being asked, and the lack of central coordination and synthesis.

During this time, Zuga (1994) completed an analysis of 220 doctoral studies in technology education. She too noted the reliance on survey research methods and a focus on curriculum and instruction issues. She recommended focusing our research efforts on (a) the inherent value of technology education, (b) cognition and conceptual attainment with respect to technology education, (c) the ideology and inherent biases that limit access for all students, (d) public attitudes and receptivity to technology and technology education, and (e) curriculum materials in order to implement technology education for all students.

The American Association for the Advancement of Science (AAAS) hosted a conference on technology education research in 1999. During this conference, Foster (1999) and Zuga (1999) revisited these and related issues. The organizers of this conference forwarded the notion that there was a strong argument in favor of technology education, but that the subject "has largely failed to materialize as a school subject in the U.S." (i.e., as a required aspect of general education). In response, Foster (1999) noted that a solid agenda and high-quality research were not adequate to address the issue of technology education as a required subject for all students. Throughout the conference, there was general agreement regarding the importance of research for the future of technology education and that more researchers were needed (Zuga, 1999).

Lewis (1999) synthesizing the discussion to date, proposed eight questions that could provide a "basis for inquiry" for the field. These included questions relating to (a) technological literacy, (b) conceptions and misconceptions of technological phenomena, (c) perceptions of technology, (d) technology and creativity, (e) gender in technology classrooms, (f) curriculum change, (g) integration of technology and other schools subjects, and (h) the work of technology teachers. He cautions his readers that we should not intentionally or accidentally "box in" researchers and challenges researchers in the field to "find their own questions."

National Center for Engineering and Technology Education

A major development in Technology and Engineering Education research has been the infusion of National Science Foundation (NSF) funding to the National Center for Engineering and Technology Education (NCETE) project housed at Utah State University. NCETE is a partnership between nine universities, two professional associations, and a private educational research organization. NCETE's mission is "to build capacity in technology education and to improve the understanding of the learning and teaching of high school students and teachers as they apply engineering design processes to technological problems" (http://ncete.org/flash/index.php). NCETE sponsored its first cohort of doctoral candidates at the universities in April 2005, and have generated several dissertations to date.

Regarding research, NCETE's goals are to

- "define the current status of engineering design experiences in engineering and technology education in grades 9 – 12;
- "define an NCETE model for professional development by examining the design and delivery of effective professional development with a focus on selected engineering design concepts for high school technology education;" and
- "identify guidelines for the development, implementation, and evaluation of engineering design in technology education" (www.ncete.org).

In an internal report (National Science Foundation, 2004), the staff of Centers for Learning and Teaching Program, in writing about the National Center for Engineering and Technology Education, noted that technology education was "an important, and much neglected area of K-12 formal school education" (p. 7). They went on to note that the "research base for the Center is not as well-established than the areas of mathematics and science education, particularly relative to cognitive learning" (p. 7).

Problem, Purpose, and Limitations

It is evident from this brief literature review, that there has been significant amount of effort to expand the research base supporting technology and engineering education. However, it is unclear the extent to which recent graduate TEE research has addressed these and related issues. Further, the direction and findings of recent graduate TEE research is unknown. While graduate research is not the only body of research being conducted my researchers in the field, it does represent a major body of research that warrants independent analysis.

The purpose of this study was to amass as comprehensive a collection of dissertations and theses in technology and engineering education as possible, and to conduct a modified meta-analysis of this body of research. It was guided by the following research questions:

1. What graduate research has been completed during the period of 2000 – 2009 and at which institutions?
2. What methods were used, and what keywords and other descriptors were used to describe the research?
3. What were the major topics and themes of this research?

The current study was limited to dissertations and theses completed between 2000 and 2009 that were identified using the ProQuest search engine. Additional studies were identified from the NCETE web site. Two studies were identified because they were known to the author. The possibility exists that there are others that have been inadvertently omitted. The sample is limited to studies that were clearly within industrial technology education, technology education, and technology and engineering education.

Methods

This study was a modified meta-analysis as the diversity of the studies did not allow for the creation of a set of common variables. The primary method was content analysis of dissertation and thesis abstracts. The list of research method categories comes from a synthesis of lists provided by Borg and Gall (1989) and Cohen and Manion (1984). The methods employed in this study were those used in Foster's 1992 study. A major difference between this study and the 1992 study was that in the previous study, the author made numerous efforts to collect unpublished manuscripts from multiple sources (e.g., contacting graduate coordinators and even traveling to university libraries). As stated above, this study was limited to those studies located primarily through "on-line" searches.

The dissertations and theses were identified using the ProQuest search engine and multiple searches using such key terms as technology education, engineering education, engineering and technology education, technology and engineering education, and industrial technology education. Approximately 200 studies were identified. After careful review to ensure that the study pertained to the technology and engineering education field, a total of 74 studies were included in the final pool. The abstracts, and in some cases the full report, were reviewed to determine the university offering the degree, date completed, the research method employed, the keywords and subject descriptors, and the topic/focus of each study.

Results

The results of this study will be reported in sections based on the three research questions used to guide the study.

1. *What graduate research has been completed during the period of 2000 – 2009 and at which institutions?*

Table 3. *Degrees earned by year and the focus of the study by educational level.*

2000	9	K-12 Education	44 (59%)
2001	2	Post-Secondary Education	17 (23%)
2002	5	Neither/Both	13 (18%)
2003	9		
2004	8		
2005	5		
2006	6		
2007	6		
2008	13		
2009	11	N = 74	

As stated above, a total of 74 dissertations/theses were included in this analysis. Table 3 provides a summary of the degrees earned by year and the educational-level focus of each study. On average, there are 7.4 studies per year with the majority (59%) focused on the K-12 educational level. As noted above, there is good reason to believe that additional studies were completed during this time period and were inadvertently omitted from analysis. While it is too soon to declare a trend, it is noteworthy that there was a marked increase in studies in 2008 and 2009.

Table 4. *Universities Offering the Degree*

North Carolina State University	11
The Ohio State University	9
University of Minnesota	5
Utah State University	4
Old Dominion University	3
Virginia Polytechnic Institute and State University	3
Nova Southeastern University	2
Purdue University	2
University of Central Missouri	2
University of Georgia	2
University of Illinois - Urbana/Champaign	2

Others with one each: Alabama State University; Andrews University; Central Michigan University; Clemson University; Colorado State University; Duquesne University (PA); Immaculata College; Indiana University; Indiana University of Pennsylvania; Jyvaskylan Yliopisto (Finland); Kent State University; McGill University (Canada); Royal Roads University (Canada); Southern Illinois University at Carbondale; Texas Tech University; The University of Nebraska – Lincoln; The University of Wisconsin – Madison; University of California - Los Angeles; University of Maryland, College Park; University of Massachusetts – Amherst; University of Missouri – Columbia; University of Pittsburgh; University of South Carolina; University of South Dakota; University of South Florida; University of Tennessee; University of Toronto (Canada); University of Wyoming

The institutions granting the degrees included in this study are listed in Table 4. Eleven institutions contributed multiple dissertations/theses for a total of 45 (61%) studies. Interestingly, two institutions (North Carolina State University and The Ohio State University) accounted for 20 (27%) of the total. It is also interesting to note that three of the studies come from Canadian universities and one from a Finnish university.

2. *What methods were used, and what keywords and other descriptors were used to describe the research?*

Table 5. *Research methods employed*

	f	%
Survey (1)	23	31.1
Delphi (1.1)	5	6.8
Observation (2)	0	0.0
Causal-Comparative (3)	4	5.4
Correlational (4)	5	6.8
Experimental (5)	3	4.1
Quasi-Experimental (6)	11	14.9
Test Development (7)	0	0.0
Observational - Participant (8)	1	1.4
Observational - Non-part. (9)	1	1.4
Case Study (10)	15	20.3
Evaluation (11)	0	0.0
Research & Development (12)	0	0.0
Historical (13)	1	1.4
Philosophical (14)	1	1.4
Combination (15)	4	5.4
Total	74	100.0

Table 5 provides a summary of the methods used to complete each study. When combined, the survey and Delphi methods comprise the method used in 37.9% of the studies. The case study method was employed 20.3% of the time. A total of 19% used experimental or quasi-experimental methods. Qualitative methods were employed 25.5% of the time.

Table 6. *Keywords used by author to categorize the study*

Technology education	26
Technology & technological literacy	10
Teacher education; technology teacher education	9
Industrial arts	6
Problem solving; finding; efficiency	6
Science; science and technology education	6
Learning; learning style; learning system	5
Curriculum & curriculum consonance	4
Elementary school	4
Self-efficacy	4
Standards for Technological Literacy	4
Cognition, cognitive apprenticeship, profiles	3
Engineering and technology education	3
High school	3
Industrial technology; education	3
Professional development	3

Table 6 contains an abbreviated list of keywords used by the author to describe the study and to provide one of the means of locating the study when using an electronic search engine. The reader should be aware that it is likely that the database software (in this case, ProQuest) also generates keywords by breaking down the title into key concepts. Consequently, it seems that the current Subject category in ProQuest is closer to the Keyword category in the former Dissertation Abstracts International. Readers should also note that authors are allowed to provide multiple Keyword descriptors per study.

What were the major topics and themes of this research?

The topic/theme of each study was determined using two methods. The first was simply listing and summarizing the Subject descriptor provided by the author. The second method was a subjective analysis of the content of the study by this researcher. Table 7 contains an abbreviated list of Subject descriptors.

Table 7. *Subject descriptors used by author to categorize the study*

Vocational education	26
Educational software	24
Curricula & curriculum development	17
Secondary education	16
Teacher education	14
Teaching	12
Educational technology	10
In-service training	9
Educational psychology	7
Industrial arts education	6
Elementary education	5
Higher education	5
School administration	5
Educational evaluation	4
Science education	4
Mathematics education	3

The Subject descriptor used most frequently is vocational education (26 times) followed by educational software (24 times), curriculum and curriculum development (17 times), and secondary education 16 times). Readers should note that authors are allowed to provide multiple Subject descriptors per study.

Table 8. *Topic/focus of the studies*

Effectiveness of instructional activities	15
Acceptance/perception of TE or TEE	10
Professional/political issues	8
Diversity/inclusion	7
Cognition/problem solving	6
Program/project evaluation	6
Teacher preparation	6
Values of TE/TEE as general education	6
Inclusion of engineering in TE	5
Instructional technology	5
Nature/testing of technological literacy	5
Teacher in-service/professional development	5
Acceptance/use of Standards for Tech. Literacy	3
Recruiting to STEM degrees/careers	3
TE/TEE curriculum development	2

Table 8 contains the results of a subjective analysis of each study (note: studies may fit more than one category). A significant number of the studies focused on testing specific instructional activities to determine their effectiveness. The second most common focus was assessing the acceptance/perception of technology education, and technology and engineering education, followed by professional and political issues.

Discussion

The purpose of this study was to conduct a modified meta-analysis of dissertations and theses completed from 2000 to 2009. The total number of studies found that were clearly in the field (i.e., industrial technology education, technology education, and technology and engineering education) was 74. The titles and abstracts, and in some cases the full report, were reviewed to determine the university offering the degree, date completed, the research method employed, the keywords and subject descriptors, and the topic/focus of each study. This study was basically a replication of Foster's (1992) early study.

It was noted in the 1992 study that one of the goals for the study was that it would serve as a benchmark for future studies and to a limited extent it does so for this study. However, it should be noted that the 1992 study included dissertations and theses from six fields of education and not just technology and engineering education. Of the 503 studies analyzed in the previous study, only 88 were categorized as Industrial Arts/Technology Education studies; a separate analysis of those studies was not completed in the 1992 study.

The data clearly indicated that the majority of the studies completed in technology and engineering education from 2000 to 2009 were focused on K-12 education (59%). The greatest percentage of those studies was completed using the survey methods (31.1%). A total of 28% of the studies could be categorized as status studies. The studies were completed at 39 different doctoral granting universities with 11 universities accounting for 45 (61%) of the studies. In forty-five cases, the studies were described using the following keywords: technology education (26), technology and technological literacy (10), and teacher education/technology teacher education (9). A subjective analysis of the topics revealed significant diversity; the topics occurring most often were (1) effectiveness of instructional activities, (2) acceptance/perception of technology education or technology and engineering education, (3) profession/political issues, and (4) diversity/inclusion issues.

On one hand, it is possible to make the case that very little has changed since 1992. The group of dissertations and theses analyzed in the current study also tend to represent a set of stand-alone studies that do not build on recognized theory, with a significant percentage of them using descriptive analyses. However, this analysis does not give us a complete picture. First, there was a marked decline in the percentage of survey studies (48.7% to 31.1%) and a sharp increase in the use of the case study method (2.8% to 20.3%). Second, there was a definite shift in the questions being asked. It can be argued that additional movement is needed, but it is clear that more work was done relative to diversity, cognition and problem solving, and the nature of technological literacy. Third, as was noted in the first point, there was a sharp increase in the number of qualitative designs.

A study of doctoral granting programs was completed in 1981 (Koble, 1981). The purpose of the study was to determine the characteristics of the programs and to rank the programs. The author reviewed programs at 27 institutions. Foster (2008) noted that the majority of those programs listed in Koble’s study were no longer in existence. As noted above, the 74 dissertations and theses were awarded by 39 institutions. Only nine of those institutions were listed in Koble’s study. The data indicate new “players in the game” and some growth in programs that have been around for many decades. However, it is clear that the number of researchers in the field has remained small and that there is still a need for more (Foster, 1992; Zuga, 1999).

This analysis is encouraging. It is clear that the increase attention to research in the field has resulted in positive developments. Progress is being made. It is also encouraging to note a significant increase in funding for research in the field as evidenced by the NCETE project. Additional efforts of this magnitude are needed. However, we cannot ignore the fact that more work is needed, especially in the development of a sound research base for the field. It is imperative if we are to continue to marshal and expand support for our efforts. Technology and engineering education is important to our country and research is important to the continued development of technology and engineering education.

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Book Review

Using Technology with Classroom Instruction that Works

Krista L. Bowen

Pitler, H., Hubbell, E.R., Kuhn, M., & Malenoski, K. (2007). *Using technology with classroom instruction that works*. Alexandria, VA: Association for Supervision and Curriculum Development. $24.00 (paperback), 242pp. (ISBN: 1416605703)

Do you feel like you need a guide to help you become an effective teacher in the digital world? I see many of my colleagues struggle with incorporating technology into their classrooms, as do I. I believe that technology should be integrated seamlessly into the curriculum; it should not be taught as an isolated subject. I have found a book that helps teachers slowly move toward the integration of technology into the curriculum.. *Using Technology with Classroom Instruction that Works (*2007) takes Robert Marzano's book, *Classroom Instruction That Works* (2001), and connects Marzano's nine instructional strategies with available technologies.

Using Technology with Classroom Instruction that Works (2007) was written by Howard Pitler, Elizabeth R. Hubbell, Matt Kuhn, and Kim Malenoski. Pitler is an Apple Distinguished Educator and National Distinguished Principal. His experiences as an educator and principal at a technology magnet school helped to form the team of authors for the book. Elizabeth R. Hubbell is a former Montessori educator, who brings her expertise in discovery learning to the team of authors. Matt Kuhn is a former secondary science teacher and administrator, who brings his passion for using technology in teaching. Kim Malenoski has experience with education at the school, district, state, and national levels. Her experience helps provide practical guidance to help make busy teachers' lives easier. These authors collaborate to create a useful and supportive guide to move teachers slowly into technology integration.

Pitler, Hubbell, Kuhn, and Malenoski take Marzano's nine instructional strategies and offer ways to take these strategies and incorporate technology. Pitler et al. (2007) use research conducted by Schacter and Fanano (1999) when they state that "applied effectively, technology implementation not only increases student learning, understanding, and achievement but also augments motivation to learn, encourages collaborative learning, and supports development of critical thinking and problem-solving skills." By using

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Marzano's instructional strategies, Pitler et al. make technology implementation simplistic and relevant for teachers with little to no technology experience.

Pitler et al. use applications such as *Microsoft Word, PowerPoint, Kidspiration,* and *Gizmo* to help in the lesson planning process. They walk their readers through planning for lessons, the different types of software applications that can be used in the lessons, websites to support lesson planning, and suggested lessons for certain skills. Each chapter in this book is structured in a very similar way: a short overview of the targeted instructional strategy, as suggested by Marzano, suggestions and examples for using the strategy in the classroom, and many examples of, or references to, technologies that support the strategy.

The authors start the book by focusing on graphic organizers, websites or tools that help in gathering data, and the creation of objectives and rubrics. Moving into chapter two, the focus is on tips to help you provide feedback for your students. They explain to the reader how to edit in the *Microsoft Word* program, designing questions for classroom response systems, grading software, and the uses for blogs and wikis. Chapter three offers ways that teachers can give their students recognition. Recognition may include awarding a certificate or displaying their work through showcases or picture galleries. Chapter four focuses on graphic organizers that can be created in programs such as *Kidspiration*. Nonlinguistic representation is addressed in chapter five, covering many areas of the curriculum. This can include charts, graphs, pictures, movies, and even video clips that can be created by the teacher or the student. Summarizing and note taking tips follow in the chapter six, which was the most enlightening chapter for me. There are many functions mentioned in this chapter that I was not aware that my computer could perform. The authors give teachers many examples of how *Inspiration* or *PowerPoint* can be used to take notes. Chapters seven and eight address cooperative learning and reinforcing effort. Cooperative learning is very important for helping students to construct new meaning or understand content with the help of their peers. Reinforcing effort is another important strategy that I feel most teachers overlook. It is important that students recognize their efforts and how it effects their achievement. The last chapters address the higher order thinking skills, homework, and planning for technology in the classroom. The appendix stresses the importance of providing your students with Internet safety instruction and instruction about fair use and copyright laws. All of these chapters cover how to use technology while using Marzano's instructional strategies. However, it is still important to keep your focus on the state standards and make technology a seamless part of your classroom instruction.

Of all the books that I have read dealing with technology, I feel that this was the most beneficial for me as a classroom teacher. It is easy to read and goes into great detail in the steps to follow in order to complete tasks that the book suggests. The book offers many websites, and the few that I tried were all still available. This book can be considered a guide that assists teachers in how to plan for technology use in their classrooms with a high level of confidence. By using technology with effective instructional strategies, students' motivation and achievement should increase. This book is a great guide for teachers who need support and also provides ideas for teachers who are already doing a good job of integrating technology in their teaching.

Miscellany

Scope of the JTE

The *Journal of Technology Education* provides a forum for scholarly discussion on topics relating to technology and engineering-related education. Manuscripts should focus on technology and engineering-related education research, philosophy, and theory. In addition, the *Journal* publishes book reviews, editorials, guest articles, comprehensive literature reviews, and reactions to previously published articles.

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