

INTEGRATIVE STEM EDUCATION AS “BEST PRACTICE”

7th Biennial International Technology Education Research Conference
Queensland, Australia, Paper presented 12/8/12

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[Reference citation: Sanders, M. E., (2012). Integrative stem education as best practice. In H. Middleton (Ed.), Explorations of Best Practice in Technology, Design, & Engineering Education. Vol.2 (pp.103-117). Griffith Institute for Educational Research, Queensland, Australia. ISBN 978-1-921760-95-2]

Abstract

In accordance with the conference theme—“Exploring Best Practice in Technology Design & Engineering Education”—I make a case in this paper for investigating “integrative STEM education” as a prospective best practice in technology education. I begin with an embellished operational definition of integrative STEM education and follow that with an extensive rationale for investigating the integrative STEM education pedagogical model as a technology education best practice. In the latter part of the paper I discuss the “design experiment” research methodology (Brown, 1992; Collins, 1992) and make the case that technology education researchers employ this methodology in their investigations of integrative STEM education. Design experiment methods are ideally suited to investigating innovative pedagogies and would benefit technology education by concurrently improving the integrative STEM education pedagogical model while generating new theories of technological learning, S, T, E, & M learning, and integrative STEM learning.

In accordance with the conference theme—“Exploring Best Practice in Technology Design & Engineering Education”—I make a case in this paper for investigating “integrative STEM education” as a prospective best practice in “technology education” (a term used throughout this paper to refer *collectively* to the field by that name in the United States as well as parallel fields elsewhere in the world, such as “Design & Technology,” Technology & Engineering Education,” etc.). I begin with an embellished operational definition of “integrative STEM education” and follow that with an extensive rationale for investigating the integrative STEM education pedagogical model as a technology education best practice. In the latter part of the paper I suggest a research methodology for investigating integrative STEM education and discuss issues relating to the thesis of this paper.

The very notion of best practice presents a dilemma, as we really cannot know an educational practice to be a *best* practice until we have investigated it to make that determination. Moreover, the determination of best practice is socially constructed and thus subjective/political in nature. In America, best practice is usually justified by declaring it “standards-based.” But that, too, is a claim often made without evidence. Moreover, standards may be dated and relatively vague in their attention to both content and instructional method. For these reasons, it makes sense to go into further investigation of best practice candidates, as is suggested herein.

Why “Integrative STEM Education”?

Though the term “STEM Education” has been *worn out* in the United States, there has never been agreement regarding its meaning. Sanders (2008) labeled this phenomenon

“STEMmania” and encouraged the field to abandon “STEM education” for “integrative STEM education.” In addition to the serious problems created by the hopeless ambiguity of STEM education, I’m troubled that the use of that phrase has further marginalized Technology Education in the United States, as it has all too often been employed to generate new funding streams limited to science and mathematics education. The operational definition of integrative STEM education prevents that sleight of hand.

Throughout most of the 20th century, industrial arts educators in the United States focused on teaching industrial processes to boys and girls “for the values which such study affords in one’s everyday life, regardless of his occupation” (Bonser & Mossman, 1923). In the past few decades, the focus of technology education has shifted to “technological literacy for all,” as described in *Standards for Technological Literacy (STL)* (ITEA, 2000). The goal of technological literacy for all begs this question: *Shouldn’t a technologically literate person in the 21st century be expected to possess the knowledge and ability to apply basic math, science, and engineering concepts and practices in designing, making, and evaluating solutions to authentic problems?* Consider that the *Next Generation Science Standards* (NGSS) call for:

a commitment to fully integrate engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry in classroom instruction...and by according core ideas of engineering and technology the same status as core ideas in the other major science disciplines” (NGSS, 2012, 1).

It seems to me that “integrative STEM literacy” would be a better name (for what’s described immediately above) than “science literacy” or “technological literacy.” But by whatever the name, technology educators *should be playing a prominent role in delivering / investigating it.*

Integrative STEM Education Defined

In September 2005, The Technology Education faculty at Virginia Tech launched an innovative STEM Education graduate program that recruits science, technology, engineering, mathematics, and elementary teachers/administrators who enroll to study teaching, learning and educational research at the intersections of these disciplines (Sanders & Wells, 2005). From the onset, the program philosophy was about intentionally situating the teaching/learning of science and mathematics concepts and practices in technological/engineering design-based instructional activities. When it became clear that “STEM education” had become hopelessly ambiguous, Sanders proposed alternative program names that might be more descriptive of the program’s philosophy than was “STEM education” as well as a number of carefully worded operational definitions that would capture the essence of the ideas on which the new graduate program had been founded. After numerous discussions, the faculty (Sanders and Wells) agreed upon “Integrative STEM Education” with the following definition:

Integrative STEM education refers to technological/engineering design-based learning approaches that *intentionally* integrate the concepts and practices of science and/or mathematics education with the concepts practices of technology and engineering education. Integrative STEM education may be enhanced through further integration with other school subjects, such as language arts, social studies, art, etc. (Sanders & Wells, 2006).

The intent of this operational definition was to *exclude* pedagogical approaches that do not purposefully situate the teaching and learning of STEM concepts and practices in

technological/engineering design-based pedagogy. Moreover, only technologies that are integral to designing, making, and engineering were to “pass” for the “T” in this definition. That is, using one or more instructional technologies to teach science and/or math concepts and practices would *not* constitute “integrative STEM instruction” because it wasn’t consistent with the operational definition. Table 1 provides a list of *selected* characteristics of integrative STEM that further describe its nature.

Table 1
Selected Characteristics of Integrative STEM Education

<p>Learning outcomes: As a result of one or more semesters of K-12 integrative STEM education, students will be able to:</p> <ul style="list-style-type: none"> ▪ demonstrate integrative STEM knowledge and practices; ▪ effectively use grade-appropriate S, T, E, & M concepts and practices in designing, making, and evaluating solutions to authentic problems; and ▪ demonstrate STEM-related attitudes and dispositions.
<p>Scope: Integrative STEM education...</p> <ul style="list-style-type: none"> ▪ is appropriate for <i>all</i> K-PhD grades / students; ▪ is <i>not</i> intended to supplant S, T, E, & M instruction that is more effectively taught non-integratively; ▪ may be implemented by one or more S,T,E, or M teachers in one or more classrooms / class periods; ▪ may be implemented during and/or after the normal school day; and ▪ should be thoughtfully and effectively articulated across multiple school grades/bands.
<p>Pedagogy: Integrative STEM education pedagogy:</p> <ul style="list-style-type: none"> ▪ is consistent with accepted learning principles (e.g., Bransford, et al., 2000; Bruning, et al., 2004; Ormrod, 2012); Eberly Center for Teaching Excellence (2012) ▪ may be interdisciplinary, transdisciplinary, or multidisciplinary in nature (Drake, 2007); ▪ purposefully engages students in integrative thinking that ranges from simple to complex; ▪ purposefully engages and assesses students in the application of grade-appropriate S, T, E, & M concepts and practices in designing, making, and evaluating solutions to authentic problems; ▪ provides a robust context for integrative STEM-related learning associated with all levels of the cognitive and affective taxonomies (Bloom, et al., 1956)

Antecedents to Integrative STEM Education

In the late 1870s, Calvin Woodward, who had earned a PhD in mathematics from Harvard University, established a lab at Washington University (St. Louis) in which he required his mathematics students to construct geometric models from drawings, so they might better understand the mathematics concepts he was teaching (Bennett, 1937). In 1880 he founded the “St. Louis Manual Training School” and has since been thought of as the founder of the field that became known as Technology Education in the United States. By situating the learning of mathematics concepts and practices in the context of wooden model exercises, Woodward was arguably the first to promote and investigate an integrative approach to STEM instruction as best practice.

Eighty years later, the USSR’s “Sputnik” mission triggered new funding for educational reform in Science, Mathematics, and Industrial Arts education (the latter being the field now known as Technology Education in the U.S.). Donald Maley, the leading voice in Industrial Arts Education at the time, put out this call for integrative STEM education:

It is at this point as never before in the history of education that Industrial Arts can enter into its own with one of its true values recognized. “Where else in the school is there the possibility for the interaction and application of mathematical, scientific, creative, and manipulative abilities of youngsters to be applied in an atmosphere of references, resources, materials, tools, and equipment so closely resembling society outside the school?” (Maley, 1959, 258-259).

While Maley’s response to his own rhetorical question was to develop his secondary level *Research and Experimentation* course, which purposefully situated mathematics and science in the context of technological activity, most others in the field continued to focus their energies on instructional *content* rather than *method*. A half-century later, his “R&E” class might still be considered a best practice in technology education.

S, T, E, & M Education Communities Validate Integrative STEM Education as Best Practice

Best practices are validated by the communities in which they are implemented. This process begins with the introduction of new instructional materials and practices, typically through curriculum development, publication of supporting materials, and professional development. Early adopters within the community begin to implement the new instructional materials and scholars in the community begin to investigate their efficacy. Through these processes, each of the S, T, E, & M education communities have begun to validate integrative STEM education over the past two decades.

Science Education Community Validates Integrative STEM Education as Best Practice

Nation at Risk (National Commission on Excellence in Education, 1983) a national report highly critical of the disconnected subject area “silos” and other shortcomings in K-12 American education triggered the current wave of education reform in the United States. In response, *Science for All Americans* (American Association for the Advancement of Science, 1989) set the tone for STEM education reform with the following theme, which runs throughout *Science for All Americans*: “It is the union of science, mathematics, and technology that forms the scientific endeavor.” (p. 25). They followed with this core idea of integrative STEM education: “The ideas and practice of science, mathematics, and technology are so closely intertwined that we do not see how education in any one of them can be undertaken well in isolation from the others.” (AAAS, 1993, pp. 321-322). Given that the AAAS represents *ten million* individuals in 261 AAAS-affiliated societies, it’s fair to say the science education community validated integrative STEM education as best practice more than 20 years ago.

The emergence, this past year of the publication titled *Next Generation Science Standards* (NGSS, 2012) from a powerful political partnership involving the AAAS, National Academy of Sciences, National Science Teachers Association, National Academy of Engineering, and the Achieve organization re-validates the integrative STEM in through statements such as:

What is different in the *Next Generation Science Standards* (NGSS) is a commitment to fully integrating engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels, and by according core ideas

of engineering and technology the same status as core ideas in the other major science disciplines. (NGSS, 2012, 1).

The NGSS includes the following (integrative STEM-validating) rationale for promoting for this turn toward engineering,: “From a practical standpoint the Framework notes that engineering and technology provide opportunities for students to deepen their understanding of science by applying their developing scientific knowledge in different contexts.”

Further validation for integrative approaches to STEM education comes from science education scholars, who have been investigating integrative STEM instructional approaches for the past two decades. (See, for example, Cajas, 2001; Crismond, 2001; Edelson, 2001; Fortus, Dershimer, Krajcik, Marx, Mamlok-Naaman, 2004; Fortus, Krajcik, Dershimer, & Mamlok-Naaman, 2005; Kolodner, 2002; Roth, 1991; Roth, 1992; Roth, 2001; Schauble, Klofer, & Raghavan, 1991; Seiler, Tobin, & Sokolic, 2001; Sidawi, 2009;).

Technology Education Community Validates Integrative STEM Education as Best Practice

Standard #3 of the national *Standards for Technological Literacy (STL, ITEA, 2000)* emphasizes the integration of technology education with science, mathematics, and other school subjects. Connections between technology and engineering are made explicit in Standard 9—“Students will develop an understanding of engineering design” (p. 99)—and implicitly throughout most of the other standards.”

Scholars from the technology education community began to get involved in the development and investigation of integrative STEM instructional materials and practices in the early 1990s and have continued those investigations to the present (See, for example, Barak, & Zadok, 2009; Brusic, 1991; Brusic & Barnes, 1992; Childress, 1996; Dearing & Daugherty, 2004; Engstrom, 2012; Hutchinson, 2002; LaPorte & Sanders, 1996; 2008; Satchwell & Loep, 2002; Merrill, 2001; Rossouw, Hacker, & de Vries (2010); Scarborough & White, 1994; and Todd, 1999).

Technology Education units within State Departments of education began developing new state-wide integrated mathematics, science, and Technology frameworks and standards (e.g., New York State Education Department, 1996); Massachusetts Department of Education, 2001) as well as new “Engineering” courses that sought to integrate content and practices across the STEM continuum (e.g., New York State Education Department, 1995; Virginia Department of Education, 1992). Similarly, *Project Lead the Way* (founded in 1996 by a Technology Education teacher) widely disseminated its middle and high school engineering curriculum that integrates STEM content and practices (Blais, 2004). And over the past decade the *International Technology and Engineering Educators Association (ITEEA)* has been developing/disseminating nationally its “integrative” K-12 *Engineering by Design* (EbD) curriculum.

In addition, over the past two decades, the technology education literature has been heavily populated with articles describing instructional materials designed to integrate technology, science, and mathematics (Sanders and Binderup, 2000) and articles addressing issues associated with the integration of STEM concepts and practices (e.g., Bunsen & Bensen,

1990; Kipperman & Sanders, 2007; Loepp, 2004; Merrill, 2001 Sanders, 2004; 2006; 2008; 2011; Williams, 2011).

Engineering Education Community Validates Integrative STEM Education as Best Practice

The National Academy of Engineering (NAE) has overseen several projects that have resulted in books promoting integrated approaches to STEM education as a means of introducing engineering content into K-12 schools (see, Committee on Standards for K-12 Engineering Education. 2010; Katehi, Pearson, & Feder, 2009). Currently, the NAE's project titled *Toward Integrated STEM Education: Developing a Research Agenda* "aims to develop a strategic research agenda for determining the approaches and conditions most likely to lead to positive outcomes of iSTEM."

Mathematics Education Community Validates Integrative STEM Education as Best Practice

The national mathematics standards (NCTM, 2000) have been less explicit in their support for integrative STEM instructional approaches than have the other national STEM standards documents. They do, however, note the importance of connecting mathematics instruction to "real world problems" and of situating mathematics in contexts other than mathematics classrooms. The new *Common Core State Standards for Mathematics* opens the door for integrative approaches through their emphasis on "cross-cutting initiatives."

A growing number of scholars have begun to investigate the teaching and learning of mathematics in K-12 technology and engineering design contexts (see, for example, Burghardt, Hecht, Lauckhardt, & Hacker, 2010); Lehrer & Schauble, 2012; Moore, 2012; Nathan, Phelps, & Atwood, 2011; Nathan & Wagner, 2011; Norton, 2007; & Stone, 2008).

Research on integrated teaching validates integrative approaches to STEM education

The research on integrated / interdisciplinary approaches to instruction has been mixed and perhaps smaller in volume than one might expect, signaling a need for further, well-designed research in this area. A number of researchers have identified benefits of integrated instruction. For example, Beane (1995) found that students in integrated curricula did as well or better on "traditional measures of school achievement" than those in separate-subject curricula. Greene (1991) found increased student interest and increased achievement scores on the *National Assessment of Educational Progress* for California students enrolled in year-long thematic units. Vars (1991) reported higher standardized achievement scores associated with integrated instruction. A number of studies have concluded that increased student interest resulted from interdisciplinary instruction. Hartzler (2000) conducted a meta-analysis of 30 quantitative studies of the effects of integrated instruction on student achievement. Among her conclusions were the following:

- 1) students in various types of integrative/interdisciplinary programs performed as well or better on standardized achievement tests than students enrolled in the usual separate subjects; 2) students in integrated curricular programs consistently outperformed students in traditional classes on national standardized tests, in-state-wide testing programs and on program developed assessments; 3) integrated curriculum is a viable alternative to traditional subject-centered programs without fear of student failure or declining standardized test scores; 4) integrated curricular

programs were successful in all four of the major academic areas: Language Arts, Math, Social Studies, and Science and at all grade levels showed the most promise; 5) Students from all socio-economic levels benefited from integrated curricular programs (159-160)

Learning Sciences and Integrative STEM Education

With the publication of *How People Learn*, (Bransford, Brown, & Cocking, 2000) the learning sciences community came together to organize and synthesize the collective body of knowledge relating to how people learn. They, and others who continue this important work organize the findings of the learning sciences into: 1) a set of factors that are known to be important for / influence learning—generally referred to as “*principles of learning*,”— and 2) a much larger set of *learning theories*—statements that provide explanations of the underlying mechanisms that contribute to learning (Ormrod, 2012).

In Table 2 below, I have juxtaposed a set of *principles of learning* synthesized from the learning sciences research by the Eberly Center for Teaching Excellence at Carnegie Mellon University with brief and somewhat parallel statements I have drawn from the integrative STEM education literature. I present this table for two reasons. First, I think it provides further support for the idea of integrative STEM education as best practice. Secondly, the statements in the right column—drawn from the literature—literature, strike me as kernels of ideas that could/should be further investigated. So, for example, the first learning principle in Table 2 deals with prior knowledge, and the column to the right indicates “integrative STEM education provides timely opportunities for students to activate prior knowledge.” I think technology education researchers should investigate that idea and others like it (e.g., others listed in the right-hand column of Table 2 and/or other ideas drawn from the literature) as I think doing so would lead to further “conjectures” and “humble theories” (as described later in this paper) about technological practice-related learning and learning in the integrative STEM education context. Moreover I think it behooves technology education to be at the forefront of that research activity.

Table 2.
Principles of Learning and Associated Integrative STEM Education Pedagogy

Theory & Research-based Principles of Learning (Eberly Center for Teaching Excellence, 2012).	Integrative STEM Education...
Students’ prior knowledge can help or hinder learning. Students come into their courses with knowledge, beliefs, and attitudes gained in other courses and through daily life. As students bring this knowledge to bear in our classrooms, it influences how they filter and interpret what they are learning. If students’ prior knowledge is robust and accurate and activated at the appropriate time, it provides a strong foundation for building new knowledge. However, when knowledge is inert, insufficient for the task, activated inappropriately, or inaccurate, it can interfere with or impede new learning.	provides timely opportunities for students to activate prior knowledge.
How students organize knowledge influences how they learn and apply what they know. Students naturally make connections between pieces of knowledge. When those connections form knowledge structures that are accurately and meaningfully organized, students are better able to retrieve and apply their knowledge effectively and efficiently. In contrast, when knowledge is connected in	provides a unique and powerful context for meaningfully organizing STEM knowledge for future

inaccurate or random ways, students can fail to retrieve or apply it appropriately.	retrieval/use.
Students' motivation determines, directs, and sustains what they do to learn. As students gain greater autonomy over what, when, and how they study and learn, motivation plays a critical role in guiding the direction, intensity, persistence, and quality of the learning behaviors in which they engage. When students find positive value in a learning goal or activity, expect to successfully achieve a desired learning outcome, and perceive support from their environment, they are likely to be strongly motivated to learn.	generates high levels of interest and motivation among a wide range of students of all ages and abilities.
To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned. Students must develop not only the component skills and knowledge necessary to perform complex tasks, they must also practice combining and integrating them to develop greater fluency and automaticity. Finally, students must learn when and how to apply the skills and knowledge they learn. As instructors, it is important that we develop conscious awareness of these elements of mastery so as to help our students learn more effectively.	immerses students in the application and integration of S,T, E, & M knowledge, skills, and practices over extended periods of time.
Goal-directed practice coupled with targeted feedback enhances the quality of students' learning. Learning and performance are best fostered when students engage in practice that focuses on a specific goal or criterion, targets an appropriate level of challenge, and is of sufficient quantity and frequency to meet the performance criteria. Practice must be coupled with feedback that explicitly communicates about some aspect(s) of students' performance relative to specific target criteria, provides information to help students progress in meeting those criteria, and is given at a time and frequency that allows it to be useful.	provides students with a specific goal (a design challenge) and ongoing feedback from peers, teachers, and from their self-evaluations of their designed/made solutions.
Students' current level of development interacts with the social, emotional, and intellectual climate of the course to impact learning. Students are not only intellectual but also social and emotional beings, and they are still developing the full range of intellectual, social, and emotional skills. While we cannot control the developmental process, we can shape the intellectual, social, emotional, and physical aspects of classroom climate in developmentally appropriate ways. In fact, many studies have shown that the climate we create has implications for our students. A negative climate may impede learning and performance, but a positive climate can energize students' learning.	creates conditions for students to engage in ongoing positive, non-threatening, and reflective social interaction with their teachers, teammates, and classmates.
To become self-directed learners, students must learn to monitor and adjust their approaches to learning. Learners may engage in a variety of metacognitive processes to monitor and control their learning—assessing the task at hand, evaluating their own strengths and weaknesses, planning their approach, applying and monitoring various strategies, and reflecting on the degree to which their current approach is working. Unfortunately, students tend not to engage in these processes naturally. When students develop the skills to engage these processes, they gain intellectual habits that not only improve their performance but also their effectiveness as learners.	engages students in a group design challenge that encourages them to take responsibility for their planning, self-assessing, self-monitoring and reflection.

Content & Method for Best Practice

Teaching of any subject requires attention to both the content to be taught and the instructional methods employed. The *STL* (ITEA, 2000) sought to identify “content for the study of technology,” and for the past dozen years, the *STL* have provided guidance for technology educators in the United States and beyond with respect to *what to teach*. Though I am proposing integrative STEM education *pedagogy* in this best practice model, I envision the technological content identified in *STL* as the *primary content* to be delivered by technology educators via the integrative STEM *pedagogy*. Historically, the field used the “project method” to address the *how to teach* question. For more than two decades,

technology educators around the world have increasingly turned to design-based instructional methods for teaching content for the study of technology. I think it's safe to say that the technology education community has long considered design-based instruction a best practice. Integrative STEM education is a design-based pedagogy that builds upon all that technology educators have learned about design-based instruction over the past two decades. In addition, integrative STEM pedagogy purposefully seeks to engage students in *using/applying* math, science, and engineering concepts and practices in designing, making, and evaluating solutions to authentic problems. One might, therefore, think of integrative STEM education as design-based technology education that authentically integrates the doing of mathematics and/or science into the design-based activity.

Investigating Integrative STEM Education

The design/make/evaluate pedagogical paradigm offers a robust learning ecology for the integration/application of engineering, science, and mathematics concepts and practices into the study of technology. And, although the science education community is now ramping up to “fully integrate engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry” (NGSS, 2012), technology teachers are *uniquely* qualified to implement and *investigate* integrative approaches to STEM education. The unique perspective technology education researchers bring to this activity will result in unique and important findings that those from other fields with differing perspectives (e.g., science education, mathematics education, and learning sciences) are not likely to discover.

While relatively few in technology education have formally employed the “design experiment” research methodology (Brown, 1992, Collins, 1992), in many ways, it is ideally suited to investigating innovative teaching practices in technology education. For that reason, among others, Janet Kolodner (1999) made this same recommendation to Technology Education researchers more than a decade ago. Ann Brown (1992) the first to describe design experiment methods 20 years ago, summarized it this way: “I attempt to engineer innovative educational environments and simultaneously conduct experimental studies of those innovations” (1992, p. 141). Trained to study human learning by observing lab rats and children in research labs rather than classrooms, Brown’s goal was to “transform classrooms from work sites where students perform assigned tasks under the management of teachers into communities of learning” (p.141).”

The point of the design experiment was twofold. On the one hand, Brown wanted to “orchestrate all aspects” of the classroom environment, based upon previous research findings, to create a designed learning ecology that would facilitate the development and testing of learning theories: “It is essential that we assess the aspects that our learning environment was set up to foster” (p. 143). Toward that end, the research team describes its assumptions about “the intellectual and social starting points for the envisioned forms of learning.” These starting points and “conjectures” drawn from the literature become kernels of the theories to be tried and tested in the design experiment. On the other hand, Brown thought of the design experiment method as “intervention research designed to inform practice.” (p. 143). In other words, data collected in a design experiment for the purpose of testing one’s theories is also used to revise any and all details of the pedagogy. For this reason, technology education researchers and practitioners would both benefit from design

experiments in the field. The likely result would be improved instruction—e.g., from good” practice” to “better” or “best” practice—and a new set of theories of technological learning.

Design experiments typically draw data from an array of sources; Brown listed 1) standard measures of content knowledge; 2) observations (audio / video recordings) of teacher planning, direct instruction, individualized coaching and responsive teaching, social interactions among teachers and students; 3) student work artifacts and student portfolios; 4) email or audio/video recordings of teacher and/or student discourse; 5) interviews with teachers and students; etc.

Documenting the “learning ecology” is an important component of design experiments (Kelly & Lesh, 2000). Studies of technology education practice would generally benefit from careful documentation of the learning ecology being investigated. In his review of *Analyzing Best Practices in Technology Education* Householder (2008) wrote: “It would be highly valuable to have more detailed, thicker descriptions of highly effective classroom practices. Richer images of outstanding instruction could withstand penetrating analyses and lead to the development of a stronger theoretical base for innovation in technology education.”

Though Brown’s tenets of design experiments remain relatively unaltered, the methods she outlined and methodological issues she addressed were revisited in special issues of *Educational Researcher* (2003) and the *Journal of Learning Sciences* (2004). Readers interested in design experiment methods will find both of these special issues helpful. For example, Cobb, Confrey, diSessa, Lehrer & Schauble, (2003) outlined five crosscutting features of design experiments:

1. The purpose of design experiments is to develop a class of theories about both the process of learning and about the means that are designed to support that learning.
2. Design studies are test-beds for innovation. The intent is to investigate the possibilities for educational improvement by bringing about new forms of learning in order to study them.
3. Design experiments create the conditions for developing theories yet must place these theories in harm’s way [by testing and revising them based upon the data collected].
4. As conjectures are generated and perhaps refuted, new conjectures are developed and subjected to test. The result is an iterative design process featuring cycles of invention and revision.
5. Theories developed during the process of experiment are humble, not merely in the sense that they are concerned with domain-specific learning processes... but also because... the theory must do real work.... The critical question that must be asked is whether the theory informs prospective design, and if so, in precisely what way? (Cobb, et al., 2003)

Discussion

The final point from Cobb, et al., (above) speaks to a gap in technology education research. Technology education researchers have *not* made the development of learning theory the

hallmark of their work. They have more generally been concerned with the broad issues of curriculum and instruction rather than with formulating and systematically investigating conjectures and “humble learning theories” regarding the nature of technological learning. Thus, the field has been prone to making broad claims with relatively little evidence to substantiate those claims. For example, technology educators in the United States are fond of saying, in effect, “Students who take Technology Education courses become technologically literate.” Although Technology Education in the United States is *grounded* in that idea, there has never been a measure of technological literacy that has really been used beyond its development phase. (Garmire & Pearson, 2006) and theories relating to technological and/or integrative STEM learning are exceedingly scarce.

And yet, there is now unprecedented interest from science, technology, and engineering educators in the idea of situating the teaching and learning of mathematics and science in the context of engineering design activity. Moreover, there have been countless unsubstantiated claims regarding the benefits of doing so. We need new theories that help to explain the mechanisms involved in technological learning, and technology education researchers should be deeply involved in that work. Integrative STEM design experiments would provide an exceptional environment in which technology educators might begin to test their humble theories and conjectures relating to technological learning. Certainly science and engineering educators will be taking on that work in the decades ahead. But technology educators will continue to approach the study of technology from a unique perspective; a perspective that would give rise to unique theories of learning that perhaps will not come from the work of those in other fields.

Integrative STEM education is, therefore, an innovative pedagogy that presents enormous opportunity for technology education researchers. The opportunity has to do with establishing integrative STEM design experiments that may be used to investigate a wide range of conjectures and humble theories regarding STEM and integrative STEM learning in a learning ecology that situates that STEM learning in the context of authentic technological/engineering design-based problem-solving.

Some Technology educators contest the idea of integrating science, mathematics, and even engineering concepts and practices into curricula designed for the study of technology. Yet, technology educators (and technologists) have always used mathematical tools and have always applied scientific concepts and practices, in their work. Moreover, it is ludicrous to think the field that now calls itself (in the United States) “Technology & Engineering Education” would *not* seek to step up its game with respect to the integration of mathematics, science, and engineering into the Technology Education curriculum. To wit, one of the stated goals of the ITEEA’s *Engineering by Design* curriculum is to “provide clear standards and expectations for increasing student achievement in math, science, and technology” (ITEEA, 2012).

To be sure, I’m not advocating design experiments as the only method for investigating best practice candidates. Because different research designs / methods each have their strengths and weaknesses, I think the field should employ the full continuum of research methods to investigate technology education teaching and learning. Nor am I advocating integrative STEM education as the only form of technology education best practice. Rather,

I'm suggesting the field would benefit from investigating new pedagogical approaches with the *design experiment* method and I'm advocating integrative STEM education as a candidate for technology education best practice consideration.

Conclusion

Nearly a decade ago, in her paper titled "Improving Technology Education Research on Cognition" (2004), Karen Zuga wrote:

Technology educators and researchers in the United States do have a history of trying to research cognition as it relates to technology education. However, the efforts have been criticized from within the profession as having too much breadth and not enough depth. There are several reasons for this state of affairs that are related to the size of the profession, as well as to the topic, technology, and the culture of the professionals. In order of priority, changing this state of affairs may best be done by: 1) creating theory for technology education; 2) identifying the constructs and concepts that students learn through technology education activities; 3) adopting a theoretical framework for research design and problems; 4) assessing the effectiveness of technology education in addressing those key concepts; 5) including teachers in research; and 6) using qualitative methods.

I confess I re-discovered Zuga's paper after *completing* the draft of this paper... and now can't help but close with it. The idea of investigating integrative STEM pedagogy with the design experiment methodology *nails* each of Zuga's six recommendations. Moreover, choosing "integrative STEM pedagogy as the focus of the design experiment will allow researchers to deeply interrogate the not-so-humble-theory that teaching science and mathematics in the context of technological/engineering design improves students' interest, understanding, and abilities in *each* of the STEM disciplines.

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