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STEM EDUCATION: THE POTENTIAL OF TECHNOLOGY EDUCATION

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Disciplinary perspectives on science, technology, engineering, and mathematics (STEM) education affords an opportunity for insights into how these respective fields of education view their roles in the schooling of America within the current context of STEM education reform. In each case one must first recognize that these Mississippi Valley Technology Teacher Education Conference (MVTTEC) responses are but microcosmic perspectives in that they are based on limited time and resources. And as a result, though drawn from valid sources, their interpretations are therefore subject to disciplinary bias. In an effort to address these limitations and challenges to presenting the Technology Education perspective on STEM education, an intentional effort was made to corroborate data gathered through a broad sweep of valid sources, including published reports and articles, research results from personal projects and courses, and personal experience gained from more than three decades of teaching and learning about science and technology education with students PreK-20.

A Century of Educational Reform – Prelude to STEM Focus

World economies, international connections, rapid continuous technological changes, the explosion of available information, threats to national security, and a plethora of other pressures are all forcing education to rethink how teaching and learning take place in the current educational system and to search for new, effective approaches to schooling. The promise of establishing science, technology, engineering, and mathematics (STEM) education as an educational reform movement portends some novel educational concept having the potential for affecting change in the educational process. The underpinnings of STEM education in the US however, are not at all new. The current focus on STEM education is following literally decades of educational reform initiatives throughout the past century beginning as early as 1892 when the National Education Association established the Committee of 10 to study schools and recommend standards for secondary education (NEA, 1894; Ravitch, 2000). As it was at the turn of the 20th Century, the main causes of educational reform continue to be large societal changes brought about by real and/or perceived threats to America economically (trade and industrial preeminence), politically (global perception/power), and maintaining its national security. Understanding this history of American educational reform is relevant to envisioning the potential that resides within STEM education reform today, regardless of the disciplinary perspective, to meet the challenges this country will face in the coming decades. As we consider STEM education in the context of schooling in America, how can the past 100 years of educational reform help us in knowing what education today must do to be successful in addressing the economic challenges of tomorrow?

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The Age of Educational Reform

According to Berube and Berube (2007), the 20th century could easily become known as the "Age of Educational Reform." Their review of American educational history reveals that there have been only three main educational reform movements – Progressive, Equity, Excellence – over the past 100 years spanning all of the 20th Century with continued impact now extending into the 21st. These movements were accompanied or driven by large societal forces external to the educational realm. An examination of the driving forces behind these three main educational reform movements provides insight into the extent to which they have shaped and continue to direct the current focus in America on STEM education.

Originating in the1890s and extending to mid 20th century the first main reform initiative was the *Progressive Education Movement* which envisioned schooling as an instrument for achieving whole scale social reform (Ravitch, 2000). Educationally, this movement expressly sought to challenge the long-standing traditional academic curriculum and replace it with a new liberal education curriculum that would more completely educate the whole child. John Dewey is considered the lead proponent of the Progressive movement and championed its main theme of applying social science to the educational process. The belief was that social science could elevate education to a science with its own set of methods and measurable ends. Fundamental to this movement was the philosophy of child-centered education, where both methods and ends could be derived from the innate needs of the child as reflected in the broader societal needs. The end of the Progressive movement came in the late 1950s when the launching of Sputnik focused attention on education as the weak link in maintaining national defense and US technological dominance. The child-centered curricula gave way to one that was designed to be much more teacher-centered, with an emphasis on science, mathematics, and foreign language content.

The early 1960s saw the birth of the civil rights movement, which took over as the dominant societal force and focused attention on the inequities within the American educational system. The result was the onset of the *Equity Reform Movement.* The aim of this second main educational reform initiative was to fulfill the progressive agenda by more completely educating the child and ensuring an equal education for the poor and disadvantaged. The civil rights movement of the 1960s and 1970s resulted in the passage of certain key legislation such as the Elementary and Secondary Education Act (ESEA, 1965), Title I, and Head Start that directly addressed inequities in education and continue today through the reauthorization of No Child Left Behind (NCLB, 2001). These brought about changes in American schooling through innovative programs that demonstrated long-term success in educating the poor. However, as the 1970s drew to a close the goal of educating the poor began to fall from political favor and was replaced with the Back to Basics movement. Attention was now shifting to the need for students to learn more content, moving education toward reestablishing excellence within a set of core subjects.

The *Excellence Reform Movement* represents the third and final main educational reform movement and is responsible for reestablishing content as the primary curricular focus within US public education. A quarter of a century ago the *Excellence* movement got its start when America was shaken from complacency by the realization that in the face of increasing foreign competition it was loosing its global economic dominance. It was the landmark document *A*

Nation At Risk: The Imperative for Educational Reform prepared by the National Commission on Excellence in Education (NCEE) in 1983 that launched this movement. In its opening sentences the NCEE claimed that “Our nation is at risk. Our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world.” The report was written as a political document placing blame for the country’s fall from dominance squarely on the soft pedagogical practices of the American educational system by claiming “Our society and its educational institutions seem to have lost sight of the basic purposes of schooling, and of the high expectations and disciplined effort needed to attain them.” This political document challenged long standing national educational practices and called for society, its people and schools, to become committed to achieving excellence in all of education. At this point the agenda was set for the *Excellence Reform Movement* and focused all national education efforts on the teaching and learning of content as the corrective measure for solving the problems in schooling created by the first two movements. The content targeted represented a rather narrow band of the overall curriculum placing the primary emphasis on science, technology and mathematics. It was believed that this renewed attention on the teaching of content within these disciplines would lead the nation to achieving the excellence needed to compete globally. In retrospect, the nation had come full circle. The return to an educational system that privileged content within a narrow band of the curriculum over educational process is the very issue challenged by the Progressive movement more than 100 years ago.

Since the beginning of the *Excellence* movement in the early 1980s, curricular reform has remained singularly focused on improving student content knowledge and understanding of science, technology, and mathematics. In 1989 a clear national direction for curricular change arose in the form of *Science for All Americans* (*SfAA*) produced through the efforts of Project 2061 (AAAS). This document, as well as the *Benchmarks for Science Literacy* (*BfSL*) that followed in 1993, provided the rationale and conceptual structure that all curriculum reform efforts should adhere to in their efforts to improve student interest and proficiency in science, mathematics, and technology (SMT). The unmistakable intent behind these AAAS publications was for curricular reformers to envision the teaching of these content areas as an integrative endeavor. This intent is clearly conveyed in their concept of science as being “…the union of science, mathematics, and technology that forms the scientific endeavor…” (AAAS, 1989, p 25) and “…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). In the two decades following these AAAS publications each of the SMT education communities developed reform documents reflective of this intent. In practice, however, the schooling system continued to support separate programs and promote traditional approaches of teaching this content in isolation from one another. To this day the challenge remains for substantively bringing together isolated SMT programs within a structure that supports true collaboration and integration of content and practices.

The Lure of an Acronym

Will the umbrella acronym STEM bring disparate programs together to effectively educate students or will these programs continue to be silos?

What's in an acronym?

At first blush, looking at the overabundance of prior acronyms related to science, technology, engineering, or mathematics throughout the past quarter century the answer to this question would appear to be straight forward. What's in an acronym? Historically, acronyms in and of themselves have not proved to be particularly effective in forging programmatic collaborations. In the past decade alone acronyms related to these disciplines used by the National Science Foundation (NSF), arguably the largest facilitator of the STEM education reform, are staggering. A small representative sampling (Householder, 2007) would include:

- IMaST (Integrated Math, Science, and Technology)
- ISE (Informal Science Education)
- ISTE (International Society for Technology in Education)
- MESA (Math, Engineering, Science Achievement)
- MSP (Math, Science Partnerships)
- MST (Mathematics, Science, and Technology)
- MSTE (Mathematics, Science, and Technology Education)
- Phys-Ma-Tech (Physics, Mathematics, and Technology),
- SIMaST (Students Integrated Math, Science, and Technology)
- SMET (Science, Mathematics, Engineering, and Technology),
- SMETE (Science, Mathematics, and Technology Education), and most recently
- STEM (Science, Technology, Engineering, and Mathematics)
- TSM (Technology, Science and Mathematics)

One obstacle to acronyms bringing together disparate programs is that interpretations vary considerably across constituents based on their specific needs or perceptions. The STEM acronym is especially problematic for promoting solidarity in educational reform because it allows each discipline to perceive and present itself as the focal point (S + T + E + M), and therefore perpetuate their traditional silo approaches to teaching and learning. In particular, the "T" in STEM continues to be misunderstood by mainstream America. Though the "T" was clearly understood to be about technological literacy when presented in the foundational SMT education reform documents (AAAS, 1989; AAAS, 1993; NRC, 1996; NCTM, 2000; ITEA, 2000) and equally so by major STEM funding organizations such as the NSF, the misperception remains strong. More surprising though, is finding that this issue can be problematic even within these supportive organizations as revealed through recent years of participation as an NSF reviewer. It is all too common for particularly novel approaches for promoting collaborative, integrative practices across math and science through design-based learning where the "T" is misunderstood and the proposal is therefore ultimately not supported during the review process. The "T" continues to be perceived by many panelists as instructional or education technology whose purpose is only to enhance instruction of science or mathematics. This issue was most poignantly demonstrated during a post review debriefing session when it became necessary to clarify for the audience of national experts in their respective STEM fields that the "T" represented a discipline in and of itself whose educational goal was technological literacy for all. Misunderstandings such as this are also easy to find currently being promoted by national organizations. One such example is the National High School Alliance (2008) who, when explaining what STEM education is, defines the "T" as the "component….that allows students to apply what they have learned, utilizing computers with specialized and professional applications like CAD and computer animation. These and other applications of technology allow students to explore STEM subjects in greater detail and in a practical manner." As well, statewide STEM efforts such as those in Texas offer similar examples. The professional development efforts in Texas targeting technology and engineering are extensive and over the past few years have become well established through programs such as Texas STEM (T-STEM) Academies, MST Teacher Preparation Academies, and Engineering Summer Programs. Yet even within these efforts the "T" in STEM continues to refer strictly to instructional technologies, though recent recognition that it refers to technological literacy is expected to result in corrections to the misunderstanding (T-STEM PDI specialist, personal communiqué 10-15-08). The continued perception of the "T" being instructional technology is not surprising given that the primary use of technology in classrooms across America is still computer-based drill and practice, business applications, and information access via the web (Anderson & Ronnkvist, 1999). Furthermore, the STEM education reform movement as a whole is perceived by the general public to mean improvements targeting math and science education as indicated in recently collected state data (AACTE, 2007; ECS, 2008).

In June of 2007 the American Association of Colleges for Teacher Education (AACTE) published a report titled *Preparing STEM Teachers: The Key to Global Competitiveness* that profiled a select portion of teacher preparation programs across the nation meeting the critical need for better STEM teachers. Of the 59 STEM teacher preparation programs profiled within the 28 states included in the report, there were only 11 who together reported a total of 9 programs that specifically addressed the preparation of engineering or technology education teachers. By far, the majority (85%) of the 59 profiled programs were focused on preparing teachers of science and mathematics. As well, in a report by the Education Commission of the States one year later on STEM initiatives at the high school level (ECS, 2008), data gathered from state statutes, rules and regulations, and state education agency web sites showed science and mathematics content areas remain the primary focus. Specifically, data collected indicate that where STEM initiatives are present, they target predominantly math and science content and/or teachers: 38 states use financial incentives to recruit predominantly math and science teachers; only three states require end-of-course exams for technology or engineering; no schools reported technology or engineering teachers within their critical STEM shortages; Utah and Texas are alone in having STEM professional development (PD) for technology education or engineering. Despite nearly a decade of growing attention on the need to improve STEM education in America, the dichotomy continues between the nation's call for change and the ability of America's educational system to implement that change. For all practical purposes with respect to PK-20 STEM education in the US, at present the evidence points to business as usual. The educational practice in PK-20 STEM disciplines continues to maintain a predominantly "silo" mind set, singularly focused on mathematics and science. Yet despite these findings, there is still good reason to remain optimistic regarding the influence of the STEM acronym.

Ascertaining the effect of but one acronym among hundreds on bringing disparate programs together is not easily determined. The better question to ask might be “What cumulative effects can be found from the initiatives behind these acronyms in promoting collaborative approaches to teaching and learning among the STEM fields?” Answering this question is more feasible and likely revealed through results of sustained efforts supporting the excellence reform movement these past few decades. One very recent and powerful indicator comes in the form of the “Enhancing Science, Technology, Engineering, and Math (STEM) Education Act of 2008” (eSTEM Act, H.R. 6104) that was simultaneously introduced in both the U.S. House and Senate in June of 2008. This “eSTEM Act” bill seeks to ensure America’s global competitiveness through significant improvements in STEM education by:

- Raising to committee status the STEM Education Subcommittee of the President’s Office of Science and Technology Policy with a mandate to design coherent national STEM strategies
- Create an Office of STEM at the U.S. Department of Education to coordinate STEM education initiatives nationally
- Establish a voluntary Consortium on STEM Education whose mission would be to develop common content standards for K-12 STEM education
- Create the National STEM Education Research Repository as a clearing house to promote replication of creative programs through open access to the latest innovations and best practices in STEM education

The intent of the eSTEM Act to bring coherence to STEM education at the program level is most clearly conveyed in its goal of developing common content standards for K-12 STEM education. Impetus for this goal comes from a number of sources, but most recently in March of 2008 through the publication of *Technology Counts 2008* by Education Week and the concurrent testimony by Bill Gates before the House Science and Technology Committee March 2008. In speaking to the committee Mr. Gates called on the nation to “indentify a smaller set of clear, high and common state standards that reflect what young people truly need to know to be successful in the 21st century…” Both the mathematics and science education communities recognize and share in this need to establish more clearly defined critical knowledge sets. Of the six main charges to the mathematics community presented in the March 2008 final report by the National Mathematics Advisory Panel, the first was “The mathematics curriculum in Grade PreK-8 should be streamlined and should emphasize a well-defined set of the most critical topics in the early grades.” (p xiii). The *Principals and Standards for School Mathematics* produced by the National Council of Teachers of Mathematics (NCTM, 2000) currently presents these critical topics as “Focal Points” through the *Curriculum Focal Points for Prekindergarten through Grade 8 Mathematics* (NCTM, 2006). The science community is taking similar action. In February 2007 officials of the National Science Teachers Association (NSTA) recognized this same need for science education and began efforts toward identifying crucial concepts of the subject. Their goal is to establish “anchors” that reflect core ideas to be emphasized at each grade level (Cavanagh, 2007). It is of note that these science anchors will be drawn from both the 1993 Benchmarks for Science Literacy (AAAS) and the current *National Science Education Standards* (NRC, 1996). The efforts at the national level to create common K-12 STEM education content standards and to develop well-defined sets of critical topics in both mathematics and science that all students should learn are very strong indicators of movement toward the integrative concept of teaching STEM as envisioned by those who crafted *SfAA* and the *BfAA.*

An additional indicator of the momentum building toward STEM education program collaborations nationally is the extent to which funding is being provided at national, state, and local levels. The largest contributor of dollars supporting STEM education in one form or another is the National Science Foundation (NSF). Their awards database (www.nsf.gov/awardsearch) clearly shows that NSF has had a long record of funding projects that target STEM education, and particularly in supporting secondary school STEM educators in upgrading both content and pedagogical knowledge in their fields since the mid 1950s (Vanderputten, 2004; Sherwood & Hanson, 2008). However, only within the last three decades do you find funding of projects that more purposefully address the educational connections between science, technology, and mathematics. At the state and local level the growing momentum is highlighted by the National Governors Association initiative on *Building a Science, Technology, Engineering, and Mathematics Agenda* launched in February 2007 (NGA, 2007a), with significant support from external funding sources such as the Bill and Melinda Gates Foundation. The *Agenda* charged governors in every state to develop and adopt policies that would address three specific recommendations for promoting collaboration among key stakeholders at all levels in STEM education:

- Aligning rigorous and relevant K-12 STEM requirements to the expectations (inputs) of postsecondary education and the workplace
- Developing statewide capacity for improved K-12 STEM teaching and learning to implement that aligned STEM education and work system
- Supporting new models that focus on rigor AND relevance to ensure that every student is STEM literate upon graduation from high school and a greater number of students move onto postsecondary education and training in STEM disciplines.

To support governors in their efforts to adopt these new policies and promote new pathways for achieving STEM literacy at the secondary level, NGA awarded $500,000 grants to six states (Colorado, Hawaii, Minnesota, Ohio, Pennsylvania, and Virginia) to improve STEM education by establishing STEM Education Centers (NGA, 2007b). These are but two examples reflecting the trend and momentum of growing support for STEM education program collaborations in America. Can further evidence be presented to demonstrate that the umbrella acronym STEM is bringing programs together? As the list of select examples drawn from the NSF awards data base provided below shows, the answer is a resounding ***yes***.

State	Date	K-12 STEM Initiatives
Arizona	1976 2004 2007	Women in Science and Engineering: experience latest imaging technology CTE program updates to align with state academic standards Bioscience High School: specializes in the sciences and related careers
Virginia	1985	Thomas Jefferson High School for Science and Technology: redesigned the school as an Integrated Biology, English, and Technology program
Illinois	1986 2004	Math and Science Academy: experimental laboratory model implementing new and experimental pedagogical techniques CTE/Vocational centers – funding for pre-engineering programs (PLTW)
Delaware	1992 2003	Delaware Science Coalition – long term focus on math/science reform Increased HS graduation requirements in math/science
New Jersey	1993	Merck Institute for Science Education – focus on improving K-8 science
California	2000	Hi-Tech High: charter school emphasizing project-based program for science, math, and engineering

State	Date	K-12 STEM Initiatives
Massachusetts	2003	Smith Summer Science and Engineering Program: girls participate in precollege integrated STEM coursework Revised state high school education standards to promote the technology and engineering standards National Center for Technological Literacy created by the Museum of Science in Boston designed K-12 curricula, standards, and professional development for technology and engineering education; by 2010 all HS graduates must pass the Massachusetts Comprehensive Assessment System exam for Science and Technology/Engineering
North Carolina	2004	New Schools Project: focus on life-sciences, engineering, biotechnology, and information technology; goal to have Learn and Earn early-college high school sites in all 100 counties by 2008
Texas	2005	T-STEM initiative: Texas High School Project designed to create 35 specialized STEM academies through a mix of charter, traditional, and early-college high schools (T = instructional technology) UTeach at UT-Austin: professional development of secondary/postsecondary teachers
Maine	2006	CTE integration into state overall academic framework with emphasis on numeracy and literacy
Kentucky	2005	Interdisciplinary CTE courses developed to meet state academic course requirements (i.e. CAD/Construction address geometry standards)
Rhode Island	2005	STEM initiatives for revising new high school science curriculum (Physics First) to include dual-enrollment options
48 States & DC	2006	Nontraditional and Alternative STEM teacher certification programs (primarily focus on M/S)
Indiana	2007	Redesigned STEM high school models (focus is on math)
Minnesota	2007	Developing model programs in digital content and STEM remediation STEM high school requirements, that include dual-enrollment options Science/Math/CTE education teacher induction and mentoring program
Ohio	2007	Ohio STEM Learning Network (OSLN) created to provide $200 million to support PK-16 STEM initiatives statewide. All partners work together to share best practices and innovative ideas for STEM education.

These K-12 level national trends are impacting education personnel decisions at both the postsecondary and state levels. New postsecondary faculty hires are increasingly being made specifically to support new university STEM initiatives, and newly created STEM coordinator positions are being filled to oversee statewide STEM initiatives. University web sites reveal that program collaboration trends in STEM education fields are also evident in the increased number of mergers between technology education and engineering programs across the country such as:

- Utah State University: Engineering and Technology Education Department in the College of Engineering
- University of Southern Maine, Department of Technology in the School of Applied Science, Engineering, and Technology

- Purdue University: Engineering/Technology Teacher Education Program in the College of Technology
- Illinois State University: Department of Technology in the College of Applied Science and Technology
- Central Connecticut State University: Technology and Engineering Education Department in the School of Engineering and Technology

Attempts in the U.S. to systemically integrate the teaching and learning of content across the STEM fields have been made for decades without large scale success. However, the difference in today's reform efforts is an authentic readiness for change at all levels. The steady progress toward globalization finds economies of the world are increasingly interdependent, interwoven, and inextricably linked. The flat world concept (Friedman, 2005) of today recognizes the onset of a global reconfiguration where regional and geographic boundaries are increasingly irrelevant (Berube & Berube, 2007). Competition for flat world economies of tomorrow demands a workforce prepared for new STEM fields, and as has been the case many times before, education is seen as the means by which we prepare that workforce. Educational systems are historically reactive entities, and in the current environment of increasing economic competition and threats to national security these systems have now reached a point of readiness for responding to and accepting new and innovative approaches to preparing the future workforce. Our educational systems of today were designed for a prior era and are ill equipped for preparing a future STEM workforce (NCEE, 2007). The challenge for the educational systems of today is their capacity to make substantive changes that will lead to improved student learning in STEM fields. However, new systems alone cannot affect the changes needed in the classroom to improve student learning. Research over the past two decades clearly shows that the single most essential factor and strongest predictor of education's capacity to respond is the educator in the classroom (Darling-Hammond, 2000, 2002; Darling-Hammond & Youngs, 2002; U.S. DOE, 2007).

STEM Education and Pedagogies of Practice

To what extent will the focus on STEM improve student learning in science, technology, engineering, and mathematics? [More succinctly: **In what ways might the focus on STEM education positively affect student learning?**]

Challenging the Norms

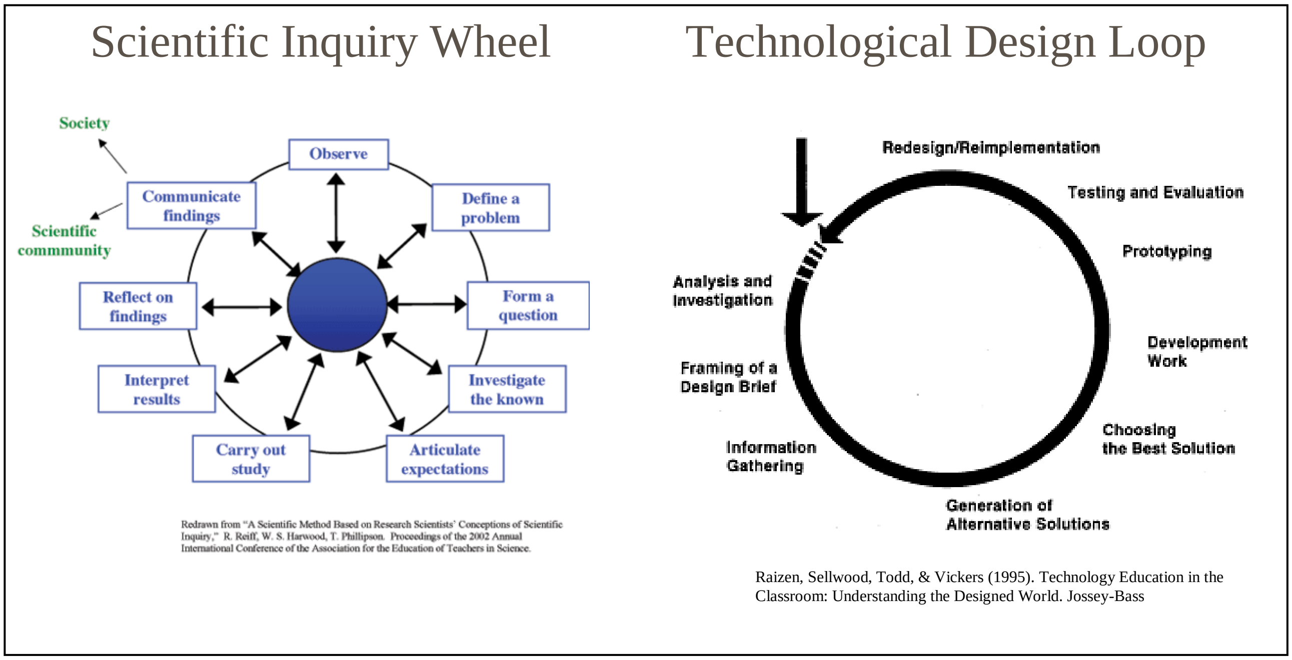
Ultimately students learn what their teachers teach them, and if the instructional approach used is one where content is fragmented and presented in isolation from other content then it will be learned that way (Humphreys, Post, & Ellis, 1981). Positively affecting students' abilities to transform knowledge into personally useful strategies for learning new content and concepts requires that teaching be improved in a way that promotes integrative strategies of student learning. This logic also begs the question "What *is* the integrative type of student learning we wish to bring about?" Cognitive science research supports the notion that *integrative* learning, as promoted through experiential education, creates the best opportunities for students to make connections in a manner that suits how the brain organizes information and constructs knowledge (Bruning, Schraw, Norby, and Ronning, 2004; Shoemaker, 1991). The brain continually searches for meaning within the patterns of information it receives and organizes that new knowledge by associating (scaffolding) it with meaning and understanding developed through prior experiences (Cromwell, 1989). Coupled with continued cognitive research on the importance of student-centered integrative instruction (Bransford, Brown, & Cocking, 2000), this provides a strong argument against the teaching and learning of isolated content and mere facts. Effective teaching presents content in meaningful contexts presented through instruction intentionally designed in a way that students will develop connections through experiences guided by purposeful inquiry.

Such findings are the very premise and rationale for integrative STEM education (Sanders & Wells, 2005), and supports the argument that integrative teaching practices, those that are based on the intentional design of instruction guided by intentional inquiry experiences, avoids the fragmentation of isolated facts that typically have little relevance to overall student learning outcomes (Lipson, Valencia, Wixson, & Peters,1993). Recent research finds that students participating in integrative STEM classes are more motivated to learn because the relevance of what is being taught becomes apparent in the connections they see among the disciplines in real-life scenarios (Satchwell & Leopp, 2002). This exemplifies a growing body of research confronting stakeholders of pre-collegiate education, from policy makers to local schools, who are increasingly under pressure to do more toward equipping students to be competitive in the STEM fields (Education Week, 2008). As a result, nationally these stakeholders are now recognizing the need to find common educational ground for better preparing students PK-12 in the STEM fields.

Toward a Pedagogical Commons

The backdrop of increased state mandates to address No Child Left Behind requirements, concern for the lack of relevancy in PK-12 curricula, and the absence of STEM practices that promote student understanding of the interconnectedness of content and concepts across STEM disciplines are providing the impetus for collaboration among the STEM fields for preparing the workforce of tomorrow. Needed is a workforce whose knowledge base must be more than a superficial understanding of isolated facts. The workforce of tomorrow must develop a knowledge base that reflects understandings of the relationships among disciplinary content that is required for solving complex problems involving interrelated causes (Benjamin, 1989). Experts across the STEM fields increasingly view integrative approaches to teaching and learning as critical for taking the nation's STEM performance to the next level (Education Week, 2008). In the past two years efforts in both the mathematics and science communities have begun to address this need through better alignment of national education standards across the STEM disciplines, with legislative support such as that provided by the eSTEM Act (2008). These efforts parallel one of the primary goals of the eSTEM Act for developing a set of common national STEM standards. Common standards will bring attention to instructional practices and alignment of pedagogical models across the disciplines. Movement in this direction is already apparent. Comparisons of pedagogical models (Fig. 1) presented by the respective STEM education fields, coupled with explanations of learning goals within their national education standards, clearly indicate points of intersect around student learning and understanding of connections, problem-solving, logic, inquiry, and design.

Figure 1. Comparison of science and technology education signature pedagogical models.



Among these models and instructional practices *integrative approaches* to teaching and learning STEM content and concepts is the pedagogical commonality.

Integrative STEM Education and Improved Learning

Integrative STEM education is the exploration of teaching and learning strategies in the context of design-based instruction, and implemented among any two or more STEM subject areas (Sanders, 2006; Sanders & Wells, 2005). The pedagogical framework that supports this approach to teaching are instructional practices that intentionally couples design-based learning and scientific inquiry with the expressed intent of facilitating knowledge acquisition and transfer of STEM content (Wells, 2008; Sanders, 2008 in press). Three instructional models, multidisciplinary, interdisciplinary, and transdisciplinary (Drake & Burns, 2004), have typically been employed for implementing integrative curricula. Calls for recognition of such integrative genre in technology education have been made before (Petrina, 1998), though transdisciplinary practices by those in the field are actually more the norm. The transdisciplinary approach addresses discipline-specific content at varying levels of complexity through focus on a central design-based problem. In so doing content is brought to bear by students on an as needed basis during the design process, which avoids the practice of presenting fragmented, isolated content in traditional approaches. In this way students recognize the relationships among the disciplinary content in relevant meaningful ways. Integrative STEM education practice such as this demonstrates the parallelisms between design-based learning and scientific inquiry that creates the opportunities for boarder crossings (Klein, 1996; Lewis, 2006). The design-based strategy as employed in technology education serves as the contextual bridge for integrative learning of STEM content. Ultimately integrative STEM (I-STEM) education fosters a blended pedagogical approach and establishes the curricular foundations that have been long supported by cognitive research. An example of this is found in a meta-analysis of 30 studies on integrative programs conducted in 2000 by Hartzler. Findings from her research revealed that students in integrative classrooms consistently outperformed those students in traditional classrooms on standardized tests and other measures. Evidence of such outcomes is similarly supported by results from research efforts to study project-based learning instruction by The George Lukas Educational Foundation (Drake, 2003; Furger, 2002).

Factors essential for effectively implementing I-STEM education are embedded within the design of instruction. The process of instructional design must begin with the intention of teaching content connections and the explicit identification of content/concept learning outcomes for the targeted disciplines. There is no disciplinary claim for integrative approaches, but technology education is unique in that it affords the curricular flexibility and the instructional environments necessary for facilitating design-based learning (DBL). As a result technology education presents the ideal educational platform for employing DBL designed to intentionally teach STEM content by engaging students in authentic learning that is guided by the method of scientific inquiry. Assessment is another critical factor in the design of I-STEM education instruction. Every explicit learning outcome must be accompanied by an equally explicit assessment of that outcome. Assessment tools must align with criteria for what constitutes integrative practices on the part of the student. Assessment criteria are derived from established goals for integrative learning, and are incorporated as both formal and informal tools, at both formative and summative evaluation points (Miller, 2005). Instructional design and classroom practices of this caliber will challenge even the most seasoned educator. There are few models currently available for current practitioners to follow, and initial attempts will likely occur by individuals within their own classrooms. Most educators are not adequately prepared with sufficient science, technology, engineering, and mathematics content or pedagogical content knowledge necessary to teach multiple subject areas simultaneously (Warner, 2003; Zubrowski, 2002). Collaboration among STEM teachers therefore affords the most promise for implementing integrative practices.

Research on integrated curricula indicates that teacher collaboration and implementation requires significant common planning time to accomplish integration (Shea, 1994). Shoemaker (1991) identified a set of essential components necessary to integrated curricula: recognized core skills and processes, curriculum strands/themes, major themes, guiding questions, unit development, and evaluation; all of which translates into attention specifically focused on the instructional design process, and where intentional design and inquiry is best facilitated by design-based learning methods. Instructional modifications to accommodate the integrative STEM approach could be in the form of two teachers working together on teaching the same topic but separately in their own classes. Or it could be a team of teachers who design thematic units or courses redesigned around interdisciplinary units of study. Satchwell & Loepp (2002) found that collaboration among STEM teachers involving a common curriculum, problem-solving model, and assessment procedures was effective in promoting integration of STEM content and concepts, and facilitated students' transfer of knowledge across disciplines. However, regardless of how teachers chose to collaborate the time necessary for collaboration was significant, and certainly any progression toward large-scale implementation of integrative STEM practices will require systemic changes at both school division and site-based levels.

Fostering New Approaches

Will a focus on STEM education bring new approaches to schooling and will it attract more students? What about teachers – are they being prepared to effectively teach STEM?

Schooling: Infrastructures and New Design Initiatives

Building on decades of research in cognitive science on teaching/learning, today's focus on integrative STEM education clearly signals the need for re-conceiving schooling in America. The collaborative model of integrative STEM education where teachers work together on planning, teaching, and assessment develops common expectations of student learning across subject areas, which positively affects student performance. More than a decade ago Lipson (1993) identified a set of the positive effects resulting from integrative teaching and learning. He found that an integrative approach provides students the opportunity to *apply knowledge and skills*, fosters the *realization of connections* among content dealt with and leading to faster recall, helps students develop *blended disciplinary perspectives*, promotes both *depth and breadth of understanding*, cultivates *positive attitudes* toward learning, and affords students sufficient quality time to more *thoroughly explore* the curriculum.

New integrative teaching practices must be accompanied with new assessment criteria for appropriate evaluation of student performance (learning outcomes) within an integrative STEM education model. Authentic, design-based problems used to guide clearly defined scientific inquiry experiences requires the design and use of assessment tools that give a true accounting of student understanding of concepts from the integrative perspective. When programs commit to integrative STEM education programs where students are expected to achieve integrative learning goals, approaches to presenting integrative experiences must be intentionally designed to achieve those goals and have tools to assess student integrative achievements (Miller, 2005). Requisite of such assessment are well orchestrated plans designed to use guided inquiry (aka Design-Based Learning – product/artifact oriented) to target specific core concepts in two or more subjects. The use of designed-based learning methods best facilitates student learning and the understanding of disciplinary content/concept connections. This is not a new concept in education. Rather, we are revisiting what research has for quite some time indicated works best to engage students and improve the learning process. Despite sufficient evidence supporting improved student learning resulting from integrative STEM education approaches, there remains the question of whether or not there are educators sufficiently prepared to develop and implement it.

It's About Teachers Not Programs

Are teachers being prepared to effectively teach STEM? From a traditional silo approach the answer is yes, but in ways that will achieve the holistic, integrative intent called for in the reform documents of the past quarter of a century (e.g., AAAS, 1989, 1993; ABET, 2000, ITEA, 1996, 2000; NCTM, 1989, 2000; NRC, 1996) the answer would be no. The major obstacles to changing traditional methods are current national/local education policies, schooling structures, and mechanisms for teacher preparation (Toulmin, 2008). Ultimately, the most significant changes needed are in teacher practices. Teacher expertise, as has been consistently and repeatedly supported through quality research, remains the single most important factor in facilitating student achievement (Darling-Hammond, 2000, 2002; Darling-Hammond & Youngs, 2002; U.S. DOE, 2007). It's about the teacher much more than it is about programs. Given the overwhelming evidence of the centrality of teacher quality to reform in American education (Darling-Hammond, Chung, Frelow, 2002; Darling-Hammond, 2007), why are teacher preparation programs still inadequate in developing teachers with the necessary STEM teaching expertise?

Our past perseveration on increasing teachers' content knowledge has not resulted in improved teaching abilities (Fennema & Franke, 1992). Instead, research finds that those teachers with more subject matter "methods" courses where they acquire the necessary pedagogical content knowledge (PCK) are more successful in promoting student engagement and improving learning (Darling-Hammond, 2007; Malcom, 2008). Furthermore, these methods are not the typical/traditional didactic strategies, but must include the type of hands-on/minds-on experiential learning required in design-based learning approaches. Wenglinsky (2002, 2000), using data from the National Assessment of Educational Progress (NAEP), found that student achievement goes up in both mathematics and science when teachers have specific professional development (pre/in-service) in hands-on teaching methods that target higher-order thinking skills. These findings argue strongly for the redesign of teacher preparation programs and other professional development efforts that provide the extensive PCK necessary for designing, developing, and implementing integrative STEM education instruction. There is also ample research evidence demonstrating the effectiveness of such programs for increasing teacher PCK and thus their teaching effectiveness, but there are few preparation programs providing this kind of professional development (Darling-Hammond, 2007 p 7; Darling-Hammond, Chung, Frelow, 2002; Monk, D. 1994). Needed are teacher preparation programs designed to involve pre/in-service teachers in joint curriculum and planning, modeling and demonstrating teaching strategies, and classroom coaching. This model for developing instructional expertise, and particularly integrative strategies, requires observation of expert teaching as demonstration of how new and/or veteran teachers are to practice, followed closely by opportunities to practice them with the expert's help (Darling-Hammond, 2007 p 8). Currently programs that ascribe to this model are the Professional Development Schools (PDS) where partnerships are established between university teacher preparation programs and PK-12 schools to design, develop, and demonstrate preeminent teaching practices. In the PDS model pre-service/novice teachers learn to teach within the classroom alongside master teachers while they are concurrently completing their university coursework. Similar to the teaching hospital concept, these pre-service teachers gain the classroom experience necessary for the scaffolding of information presented in the university courses. The PK-12/University *collaboratory* (Wells, 1999) that is created through professional development schools establishes teacher preparation environments that are uniquely positioned to create and foster the new approaches to schooling that directly addresses the need for Reformed Education (Wells, 2007, 2008). It is this *collaboratory* (Wells, 1999; Wells, Webb-Dempsey, & Van Zant, 2001) that forges the necessary common ground between university and PK-12 stakeholders leading to a reformation of teaching/learning practices in both settings.

Reformed Education – Incremental and Piecemeal

The true potential of STEM education reform lies in the opportunity to affect change in teacher practice. High quality research on instructional practices has not supported approaches that are either entirely "student-centered" or "teacher-centered." Such research indicates that student learning is best facilitated using a blend of strategies when and where they are most likely to have a positive impact under specified conditions (National Mathematics Advisory Panel, 2008). This is a basic tenant of I-STEM education, and the process by which an educator would develop an "integrative" pedagogy requires that they consider carefully their own teaching. Integrative instruction places the teacher in a position where they must reflect on what they actually do when they teach and why. They return to basic questions such as "Why have I chosen this learning objective, this strategy, and this particular technique?" What exactly am I expecting students to learn about connections among STEM content? If instruction is not explicitly designed to teach connections, such outcomes are unlikely to be achieved. Improving the design of instruction to be "intentionally integrative" (I-STEM Ed) learning holds the most promise for actually increasing the likelihood of improving student learning. Professional development for teachers, both pre-service and in-service, that establish classroom practices that include intentional design of instruction will result in teaching that is more than a series of activities, and where student learning is not left to chance. What this calls for is not educational reform writ large, but *Reformed Education* approached through well conceived and effective pre-service and in-service professional development programs. Reformed education is about recruiting and adequately preparing teachers with both the content knowledge and the pedagogical content knowledge necessary to implement the specific teaching strategies needed to effectively teach their content (Mehalik, Doppelt, & Schunn, 2005; Zubrowski, 2002).

Eyes to the Future

In the ideal sense that STEM Education has been presented within the rhetoric of national reports and calls for action to advance U.S. economic vitality and national security, the current education system is by and large not designed to support it. Specifically, the intent conveyed in the past quarter century of reform literature calls for (STEM) education to be "integrative" in its approaches, but the reality is that of continued S + T + E + M taught alone and in isolation from one another; simply more of the same. To achieve the wholesale ideal would require sustained systemic changes in secondary schooling in the form of substantive restructuring of schooling to address known barriers such as: class scheduling to allow for common planning time, for teacher collaboration, team teaching, co-design of instruction, multi-modal testing (classroom and standardized), sustainable pre- and in-service professional development, and the redesigning of teacher preparation programs (Brown, 1997) that introduce new methods that promoted integrative design of instruction and true collaborations among STEM disciplines all working toward this common goal. Yet achieving these ideals is only likely if there is sufficient evidence to convince not only the policymakers and administrators (Malcom, 2008), but the practitioners themselves who would bare the burden of implementation in the classroom. Furthermore, change of this magnitude, if not done in concert with national/state policymakers and state/local administrations, will not provide the necessary infrastructure for establishing the I-STEM education approach. The potential does indeed exist, though currently there is no real evidence of commitment on the part of the U.S. educational system (Kadlec & Friedman, 2007).

Wholesale systemic changes in infrastructure, schools, and programs are long-term goals, and are not immediately necessary in order for reform to take hold. Incremental change is good for promoting Reformed Education, and a return to focusing on the teacher and improving their ability to teach well is a key starting point. Teacher quality is central to Reformed Education. Strategies for change that focus on improving teaching practices provide the greatest potential for improving learning outcomes in our PK-12 students – our single most important national resource. Technology education at the secondary school level has the teachers, the preparation programs, and an established PreK-12 presence. What we do not have are those preparation programs that develop classroom educators with the teacher knowledge needed for *Reformed Education*. Such educators are the transformative intellectuals needed to bring about this change (Berube & Berube, 2008).

References

ABET Engineering Accreditation Commission. (2004). A*BET Criteria for Accrediting Engineering Programs.* Baltimore, MD: ABET, Inc. Author.

American Association for the Advancement of Science (1989). *Science for All Americans.* Washington, DC: Author

American Association of Colleges for Teacher Education. (2007). *Preparing STEM Teachers: The Key to Global Competitiveness.* Retrieved August 28, 2008 from http://www.aacte.org/Governmental_Relations/AACTE_STEM_Directory2007.pdf

American Association for the Advancement of Science (1993). *Benchmarks for Science Literacy: Project 2061.* Washington, DC: Author

Anderson, R. E., & Ronnkvist, A. (1999). *The Presence of Computers in American Schools.* Report No. 2. Ivinve, CA: Center for Research on Information Technology and Organizations, University of California, Irvine, and the University of Minnesota. Retrieved September 14, 2008 from http://www.crito.uci.edu/TLC/findings/Internet-Use/startpage.htm

Benjamin, S. (1989, September). An ideascape for education: What futurists recommend. *Educational Leadership, 47*(1), 8-16.

Berube, M. & Berube, C. (2007). *The End of School Reform.* Rowman and Littlefield. Landham, MD.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How People Learn: Brain, Mind, Experience, and School.* Washington, DC: National Academy Press.

Brown, C. & Smith, M. (1997). Supporting the development of mathematical pedagogy. *The Mathematics Teacher*, 90(2), 138-143.

Bruning, R. H., Schraw, J. G., Norby, M.M., & Ronning, R. R. (2004). *Cognitive Psychology and Instruction.* Columbus, OH: Pearson.

Cavanagh, S. (2007, February 28). NSTA to Provide 'Anchors' to Winnow Topics. *Education Week, 26*(25), 5-14. Retrieved March 6, 2007, from Academic Search Complete database.

Cromwell, S. (1989). A new way of thinking: The challenge of the future. *Educational Leadership, 49*(1), 60-64.

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Educational Policy Analysis Archives, 8*(1). Retrieved October 7, 2008 from http://epaa.asu.edu/epaa/v8n1

Darling-Hammond, L. (2002). The research and rhetoric on teacher certification: A response to "Teacher certification reconsidered." *Educational Policy Analysis Archives, 10*(36). Retrieved October 7, 2008 from http://epaa.asu.edu/epaa/v10n36

Darling-Hammond, L. Chung, R., Frelow, F. (2002). Variation in teacher preparation: How well do different pathways prepare teachers to teach? *Journal of Teacher Education 53*(4), 286-302.

Darling-Hammond, L. & Youngs, P. (2002, December). Highly qualified teachers: What does scientifically-based research actually tell us? *Educational Researcher*, 31(9), 13-25.

Darling-Hammond, L. (2007). *Improving the Nation's STEM Capacity: Creating a Systemic Approach.* Testimony at American Association of Colleges for Teacher Education Congressional Briefing July 21 on Preparing STEM Teachers: The Key to Global Competitiveness. Retrieved September 16, 2008 from http://www.aacte.org/Governmental_Relations/hammond_STEM_testimony.pdf

Drake, S. & Burns, R. (2004). *Meeting Standards Through Integrated Curriculum.* Association for Supervision and Curriculum Development. Alexandria, VA.

Education Commission of the States (2008, June). *High School Level STEM Initiatives.* Retrieved October 10, 2008 from http://mb2.ecs.org/reports/Report.aspx?id=1409

Education Week (2008, March). STEM: The push to improve science, technology, engineering, and mathematics education. *Technology Counts 2008.* Retrieved September 19, 2008 from http://www.edweek.org/ew/toc/2008/03/27/index.html

Fennema, E. & Franke, M. (1992). Teachers' knowledge and its impact. *Handbook of Research on Mathematics Teaching and Learning*, Grouws, D. (Ed), 147-164. National Council of Teachers of Mathematics

Fishman, B., Marx, R., Blumenfeld, P., Krajcik, J. (2004). Creating a framework for research on systematic technology innovations, *Journal of the Learning Sciences*, *13*(1), 43-76.

Friedman, T. L. (2005). *The World Is Flat: A Brief History of the Twenty-First Century*. New York: Farrar, Straus, and Giroux.

Furger, R. (2002). *Assessment for Understanding: Taking a Deeper Look.* The George Lukas Educational Foundation. Retrieved September 12, 2008 from http://www.edutopia.org/assessment-for-understanding-taking-deeper-look

Gates, B. (2008, March). Congressional Testimony to the House Science and Technology Committee, Washington, DC. Retrieved October 10, 2008 from http://democrats.science.house.gov/Media/File/Commdocs/hearings/2008/Full/12mar/Hearing_Charter.pdf

Hartzler, D. S. (2000). *A Meta-Analysis of Studies Conducted on Integrated Curriculum Programs and their Effects on Student Achievement.* Unpublished doctoral dissertation, Indiana University, Bloomington, IN.

Honda, M. & Obama, B. (2008, May). *Enhancing Science, Technology, Engineering, and Mathematics Education (STEM) Act of 2008.* H.R. 6106/S. 3047. Retrieved September 9, 2008 from http://honda.house.gov/legislation/2008/stem.shtml

Householder, D. (2007). *Selected NSF Projects of Interest to K-12 Engineering and Technology Education.* Retrieved August 27, 2008 from http://www.ncete.org/flash/research/NSF_Projects_in_ETE_Nov_15_07.pdf

Humphreys, A., Post, T., Ellis, A. (1981). *Interdisciplinary Methods: A Thematic Approach.* Santa Monica, CA: Goodyear Publishing Company.

International Technology Education Association. (2000). *Standards for Technological Literacy: Content for the Study of Technology.* Reston, VA: Author.

Klein, J. T. (1996). *Crossing Boundaries: Knowledge, Disciplinarities, and Interdisciplinarities.* University Press of Virginia, Charlottesville, VA.

Lewis, T. (2006). Design and inquiry: Basis for accommodation between science and technology education in the curriculum? *Journal of Research in Science Teaching*, *43*(3), 255-281.

Lipson, M. Valencia, S. Wixson, K., & Peters, C. (1993). Integration and thematic teaching: Integration to improve teaching and learning. *Language Arts, 70*(4), 252-264.

Mehalik, M. Doppelt, Y, Schunn, C. (2005). *Middle-School Science Through Design-Based Learning versus Scripted Inquiry: Better Overall Science Concept Learning and Equity Gap Reduction.* Paper presented at the 2005 American Education Research Association.

Malcom, S. (2008, April). *Chat Transcript* on STEM: The Push to Improve Science, Technology, Engineering, and Mathematics Education. Retrieved August 29, 2008 from http://www.edweek.org/chat/transcript_04_02_08.html

Miller, R. (2005). Integrative learning and assessment. *peerReview, Summer/Fall,* 11-14.

Monk, D. H. (1994). Subject area preparation of secondary mathematics and science teachers and student achievement. *Economics of Education Review, 13*(2), 125-145.

National Center on Education and the Economy (2007). *Tough Choices or Tough Times,* Executive Summary. Retrieved September 3, 2008 from http://www.skillscommission.org/pdf/exec_sum/ToughChoices_EXECSUM.pdf

National Commission of Excellence in Education (1983). *A Nation at Risk: The Imperative for Educational Reform.* Washington, DC: Author

National Council of Teachers of Mathematics (1989). *Curriculum and Evaluation Standards for School Mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics (2000). *Principles and Standards for School Mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics (2006). *Curriculum Focal Points for Prekindergarten through Grade 8 Mathematics.* Reston, VA: Author.

National Education Association (NEA) of the United States. Committee of Ten on Secondary School Studies. (1894). Report of the Committee of ten on secondary school studies: with the reports of the conferences arranged by the committee. Pub. for the National Education Association by the American Book Co.

National High School Alliance. (2008). *What is STEM Education?* Accessed September 14, 2008 from http://www.hsalliance.org/stem/FAQ.asp

National Governors Association (2007a). *Building a Science, Technology, Engineering, and Mathematics Agenda.* Washington, DC: Author

National Governors Association (2007b). *NGA Awards $500,000 Grants to Six States to Improve STEM Education.* News Release, Washington, DC: Author

National Mathematics Advisory Panel (2008). *Foundations for Success: The Final Report of the National Mathematics Advisory Panel.* U.S. Department of Education: Washington, DC.

National Research Council (1996). *National Science Education Standards.* Washington, DC: National Academy Press.

National Science Teachers Association (2004). *Scientific Inquiry: NSTA Position Statement.* Retrieved August 27, 2008, from http://www.nsta.org/pdfs/PositionStatement_ScientificInquiry.pdf

Partnership for 21st Century Skills (2007). *21st Century Curriculum and Instruction.* http://www.21stcenturyskills.org/documents/21st_century_skills_curriculum_and_instruction.pdf

Petrina, S. (1998). Multidisciplinary Technology Education. *International Journal of Technology and Design Education, 8*, 103-138.

Kadlec, A. & Friedman, W. (2007). *Important, But Not For Me.* Report from Public Agenda, Washington, DC. Retrieved October 3, 2008 from http://www.publicagenda.org/files/pdf/important_but_not_for_me.pdf

Ravitch, D. (2000). *Left Back: A Century of Failed School Reforms.* New York: Simon and Schuster

Sanders, M. (2006, November). *A Rationale for New Approaches to STEM Education and STEM Education Graduate Programs.* Paper presented at the 93rd Annual Mississippi Valley Technology Teacher Education Conference, Nashville, TN.

Sanders, M. (In Press). Integrative STEM education: Primer. *The Technology Teacher*, December, 2008.

Sanders, M. & Wells, J. (2005). *STEM Graduate Education/Research Collaboratory.* Paper presented to the Virginia Tech School of Education faculty, Virginia Tech.

Satchwell, R. E. & Loepp. F. (2002). Designing and implementing an integrated mathematics, science, and technology curriculum for the middle school. *Journal of Industrial Teacher Education, 39*(3), 41-66.

Shea, T. (1994). *An Ethnographic Study of Change Management During IMaST Implementation.* Unpublished master's thesis. Normal, IL: Illinois State University.

Sherwood, R. & Hanson, D. (2008). A review and analysis of the NSF portfolio in regard to research on science teacher education. E*lectronic Journal of Science Education, 12*(1), 20-38. Retrieved September 28, 2008 from http://ejse.southwestern.edu/volumes/v12n1/articles/art2-sherwood.pdf

Shoemaker, B. (1991). Integrative education: A curriculum for the twenty-first century." *Oregon School Study Council*, *33*(2), 793-797.

Smith, C. & Gillespie, M. (2007). Research on professional development and teacher change: implications for adult basic education. *Review of Adult Learning and Literacy, 7,* National Center for the Study of Adult Learning and Literacy.

Toulmin, C. (2008, April). *Chat Transcript* on STEM: The Push to Improve Science, Technology, Engineering, and Mathematics Education. Retrieved August 29, 2008 from http://www.edweek.org/chat/transcript_04_02_08.html

U. S. Department of Education (2007). *No Child Left Behind Fact Sheet.* Teacher-To-Teacher Initiative. Retrieved July 23, 2008 from http://www.ed.gov/teachers/how/tools/initiative/factsheet.pdf

Vanderputten, E. (2004, April). *Knowledge about what works for teachers: Why is it rarely used?* Paper presented at the Annual Meeting of the American Educational Research Association, Montreal, Canada.

Warner, S. A. (2003). Teaching design: Taking the first steps. *The Technology Teacher, 62*, 7-10.

Wells, J. G. (1999). *Trek 21: Educating Teachers as Agents of Technological Change*. Funded proposal submitted to the U.S. Department of Education, Preparing Tomorrow's Teachers to Use Technology (PT3) program.

Wells, J., Webb-Dempsey, J., and Kuhn-Van Zant, A., (2001). Evolutions of evaluation: Trek 21 & PT3. Proceedings of the *Preparing Tomorrow's Teachers to Use Technology.*

Wells, J. G. (2007). Key design factors in durable instructional technology professional development. *Journal of Technology and Teacher Education*, *15(1),* 101-118.

Wells, J. G. (2008). *Potentials of Integrative STEM Education in Technology Education.* Paper presented to the Virginia Tech I-STEM Education Graduate Seminar, Virginia Tech.

Wenglinsky, H. (2000). *How teaching matters: Bringing the classroom back into discussions of teacher quality.* Princeton, NJ: Educational Testing Service.

Wenglinsky, H. (2002). How schools matter: The link between teacher classroom practices and student academic performance. *Education Policy Analysis Archives 10*(12). http://epaa.asu.edu/epaa/v10n12 (accessed October 9, 2008).

Zubrowski, B. (2002). Integrating science into design technology projects: Using a standard model in the design process. *Journal of Technology Education, 13*(2), 48-67.