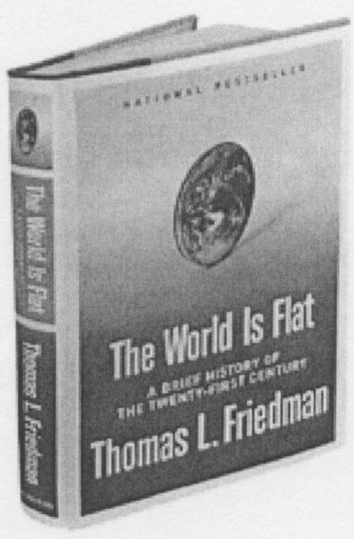
STEM, STEM Education, STEMmania

By Mark Sanders

A series of circumstances has once more created an opportunity for technology educators to develop and implement new integrative approaches to STEM education championed by STEM education reform doctrine over the past two decades.



In the 1990s, the National Science Foundation (NSF) began using "SMET" as shorthand for "science, mathematics, engineering, and technology." When an NSF program officer complained that "SMET" sounded too much like "smut," the "STEM" acronym was born. As recently as 2003, relatively few knew what it meant. Many that year asked if the STEM Education graduate program I was beginning to envision had something to do with stem cell research. That was still very much the case in Fall 2005, when we—the Technology Education Program faculty at Virginia Tech—launched our STEM Education graduate program.[1] But when Americans learned the world was flat (Friedman, 2005), they quickly grew to believe China and India were on course to bypass America in the global economy by outSTEMming us. Funding began to flow toward all things STEM, and STEMmania set in. Now, nearly everyone seems somewhat familiar with the STEM acronym.

And yet, it remains a source of ambiguity. Technology educators proudly lay claim to the T and E in STEM. But so, too, do Career and Technical educators, who (in my home state, at least) seem to have claimed the "E" as their own. Most, even those in education, say "STEM" when they should be saying "STEM education," overlooking that STEM without education is a reference to the fields in which scientists, engineers, and mathematicians toil. Science, mathematics, and technology *teachers* are STEM *educators* working in STEM *education*. It's an important distinction. In addition, there is the common misconception that the "T" (for technology) means computing, thereby distorting the intended meaning of the STEM acronym. Suffice it to say, STEM is often an ambiguous acronym, even to those who employ it.

The National Science Foundation knows what it means. For nearly two decades, NSF has used STEM simply to refer to the four separate and distinct fields we know as science, technology, engineering, and/or mathematics. Yet, some

[1] We added this as new graduate program at Virginia Tech, complementing our Technology Education graduate program, which we have no intention of relinquishing.

have suggested that STEM education implies interaction among the stakeholders. It doesn't. For a century, science, technology, engineering, and mathematics education have established and steadfastly defended their sovereign territories. It will take a lot more than a four-letter word to bring them together.

For those reasons, I am skeptical when I hear STEM education used to imply something new and exciting in education. Upon close inspection, those practices usually appear suspiciously like the status quo educational practices that have monopolized the landscape for a century. Pending evidence to the contrary, I think of STEM education as a reference to business as usual—the universal practice in American schools of disconnected science, mathematics, and technology education...a condition that many believe is no longer serving America as well as it should/might.

Introducing...Integrative STEM Education

In Fall, 2007, we realized the acronym's ambiguities were inescapable, and thus retitled our new Graduate Program "Integrative STEM Education." That was important to us because, from the onset, we intended the program to focus squarely upon new integrative approaches to STEM education and to investigate those new integrative approaches (Sanders, 2006; Sanders & Wells, 2005).[2] Our notion of integrative STEM education includes approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects. Just as technological endeavor, for example, cannot be separated from social and aesthetic contexts, neither should the study of technology be disconnected from the study of the social studies, arts, and humanities. Our Integrative STEM Education graduate program encourages and prepares STEM educators, administrators, and elementary educators to explore and implement integrative alternatives to traditional, disconnected STEM education.

A pedagogy we refer to as "purposeful design and inquiry" (PD&I) is a seminal component of integrative STEM education. PD&I pedagogy purposefully combines technological design with scientific inquiry, engaging students or teams of students in scientific inquiry situated in the context of technological problem-solving—a robust learning environment. Over the past two decades of educational reform, technology education has focused on technological design, while science education has focused on inquiry. Following the PD&I approach, students envisioning and developing solutions to a design challenge might, for example, wish to test their ideas about various materials and designs, or the impact of external factors (e.g., air, water, temperature, friction, etc.) upon those materials and designs. In that way, authentic inquiry is embedded in the design challenge. This is problem-based learning that purposefully situates scientific inquiry and the application of mathematics in the context of technological designing/problem solving. Inquiry of that sort rarely occurs in a technology education lab, and technological design rarely occurs in the science classroom. But in the world outside of schools, design and scientific inquiry are routinely employed concurrently in the engineering of solutions to real-world problems.

Many technology teachers are fond of saying they teach science and math in their technology education programs. In truth, it is exceedingly rare for a technology teacher to explicitly identify a specific science or mathematics concept or process as a desired learning outcome and even rarer for technology teachers to assess a science or mathematics learning outcome. Technology education students might very well do some arithmetic or *recognize* a scientific principle at play en route to completing a design challenge, but those design challenges are almost never conceived to *purposefully* teach a desired science or mathematics learning outcome. Thought of in this way, the notion of "purposeful design and inquiry" represents a new frontier in education—a frontier toward which integrative STEM education research and practice are targeted.

Integrative STEM education is not intended as a new stand-alone subject area in the schools accompanied by new "integrative STEM education" licensure regulations, as some might suspect. Given the amount of content knowledge necessary to be an effective science, mathematics, or technology educator, it's very difficult to imagine a new teaching/licensure program that would prepare individual pre- and/or in-service teachers with sufficient science, mathematics, and technology content expertise—and the pedagogical content knowledge—to teach all three bodies of knowledge effectively.

[2] From the onset in 2005, Virginia Tech's Integrative STEM Education Graduate Program has offered the MAED, EdS, EdD, and PhD degree options. In Fall 2008, we added a 12 semester-hour Integrative STEM Education Graduate Certificate Program. All of the Integrative STEM Education coursework was newly conceptualized and developed explicitly for these new degree options, and is available online. Programs in other universities will, increasingly, carry the "STEM Education" moniker. But to date, we are aware of no other programs—graduate or undergraduate—that focus specifically upon integrative approaches to STEM education.

Rather, Virginia Tech's Integrative STEM Education graduate program offers a new body of knowledge for current and preservice STEM educators, introducing them to the foundations, pedagogies, curriculum, research, and contemporary issues of each of the STEM education disciplines, and to new integrative ideas, approaches, instructional materials, and curriculum. In doing so, the program prepares/enables them to better understand and integrate complementary content and process from STEM disciplines other than their own. Integrative STEM education is implemented in various ways. In some cases, STEM educators implement integrative approaches within their own STEM courses/facilities. In some cases, STEM educators begin working together across their disciplines in pairs or teams. In some cases, school divisions are beginning to think about systemic changes to STEM education that incorporate integrative approaches to STEM education.

Two progressive school divisions in Virginia—Arlington County and Loudoun County public schools—have (combined) enrolled more than 20 high school teachers and administrators in our online Integrative STEM Education courses/certificate program this semester, to assist them in transforming the culture of STEM education in their school divisions. In this way, our integrative STEM education courses represent a robust professional development opportunity, wholly consistent with a new body of research that concludes professional development is most effective when site-based and sustained over an extended period of time. In effect, our courses engage STEM educators in reflecting upon integrative practice continuously from one semester to the next. Moreover, they *introduce* STEM educators to one another across disciplines through course assignments that require cross-discipline collaboration. Several or more semesters working with STEM educators *beyond* one's own discipline is a powerful means of facilitating new integrative alliances and approaches, and for developing understanding of other STEM education cultures. STEM administrators and elementary educators are also enrolling in our online courses/programs. This is exciting to us because elementary grades offer unique opportunities for integrative approaches to STEM education and are absolutely the place to begin these integrative approaches. If America hopes to effectively address the "STEM pipeline" problem, we must find ways of developing young learners' interest in STEM education and must sustain that interest throughout their remaining school years. Therein lies the real potential and promise of integrative STEM education.

Why Integrative STEM Education?

Conventional STEM Education Leaves too Many Students Behind

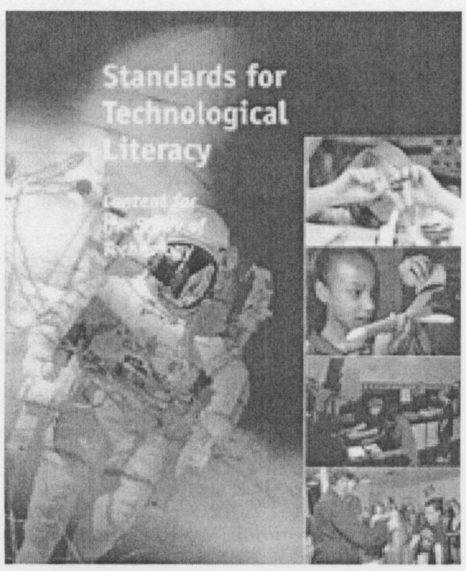
The fact that each of the four STEM education communities has engaged in massive and ongoing educational reform efforts over the past 20 years (e.g., AAAS, 1989, 1993; ABET, 2000; ITEA, 1996, 2000; NCTM 1989, 2000; NRC, 1996) is convincing evidence of the serious STEM education challenges to be addressed. The STEM education establishment has long believed STEM education hasn't been working as well as it should, and has been toiling steadfastly to make improvements. But instead of praising their successes, public concern has escalated. In recent years, the "STEM pipeline" problem—the decrease in the number of students pursuing STEM fields, particularly those from historically underrepresented populations—has been widely publicized. Much of the attention has focused on addressing the shortage of qualified science and mathematics teachers, a problem the No Child Left Behind Act (2001) has targeted. The NCLB legislation has resulted in increased attention to science and mathematics teacher education, alternative routes to licensure, and new avenues for attaining "highly qualified" teaching status.

Less attention has been paid to the infrastructure and pedagogy of conventional STEM education. Integrative STEM education challenges the assumption that more STEM educators prepared in conventional ways to teach in conventional settings is the best way to approach the problems of STEM education. Too many students lose interest in science and mathematics at an early age, and thus make an early exit from the so-called "STEM pipeline." Conventional approaches to science and mathematics education have, in fact, prepared some students to be as capable in science and mathematics as any in the world. But, at the same time, there is widespread concern regarding the large percentage of students who opt out of "rigorous" science and mathematics middle and high school courses, and for the many students who graduate high school with relatively low science and/or mathematics ability.

There is sufficient evidence with regard to achievement, interest, and motivation benefits associated with new integrative STEM instructional approaches to warrant further implementation and investigation of those new approaches. Seasoned educators understand the importance of interest and motivation to learning, constructs validated by the findings of cognitive scientists over the past three decades. It follows, therefore, that integrative STEM instruction, implemented throughout the P-12 curriculum, has potential for greatly increasing the percentage of students who become interested in STEM subjects and STEM fields. There is a distinct possibility that "STEM literacy for all" may pay greater dividends in the long run than "STEM preparedness for college entrance examinations."

Exemplar of STEM Education Reform

The implementation of new integrative STEM education approaches is a logical extension of the past two decades of STEM education reform efforts. The *central* theme of *Science for All Americans* (AAAS, 1989), which was designed to guide educational reform through 2061, is the critical importance of addressing the inherent connections among science, mathematics, and technology. *Benchmarks for Science Literacy* (AAAS, 1993) rewrote those ideas in terms that provide the fundamental rationale for integrative STEM education: "*The basic point is that 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*" [italics added]. These ideas led to the "Science and Technology" standard in the *National Science Education Standards* (NRC, 1996), which very clearly stipulates that "technological design" be taught in the science curriculum throughout grades K-12 as a way of acquiring "abilities of technological design." Some, including me, might challenge the idea of technology as science, but there can be no doubt that the ideals underlying science education reform promote integrative STEM education.



Standards for Technological Literacy.

Similarly, the technology education community has, throughout its history, promoted curricular connections with science and mathematics education. These "TSM connections" became a primary focus for technology educators in the 1990s (e.g., LaPorte & Sanders, 1995; Sanders & Binderup, 2000), and manifested in Standard #3 of *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000/2002/2007), which reads: "Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study," with subtext that focuses specifically upon connections with science and mathematics.

The flavor of integrative STEM education resonates in several of the engineering accreditation standards that grew out of the engineering education reform efforts: "(a) an ability to apply knowledge of mathematics, science, and engineering, (b) an ability to design and conduct experiments, as well as to analyze and interpret data, and (d) an ability to function on multidisciplinary teams" (ABET, 2000). The national mathematics standards—*Principles and Standards for School Mathematics* (NCTM, 2000)—aren't as explicit with regard to "integrative" approaches as are science, technology, and engineering education, but language throughout the mathematics standards encourages the teaching and learning of mathematics in the context of real-world problems. Looking beyond STEM education reform, the "Science, Technology, and Society" standard in the national social studies standards also very clearly supports connections with both science and technology education (NCSS, 1994).

Grounded in the Findings of the Learning Sciences

Integrative STEM education is grounded in the tenets of constructivism and the findings of three decades of cognitive science. Bruning, Schraw, Norby, and Ronning (2004) identified the following set of cognitive themes that resonate with integrative STEM education:

- *Learning is a constructive, not a receptive, process.*
- *Motivation and beliefs are integral to cognition.*
- *Social interaction is fundamental to cognitive development.*
- *Knowledge, strategies, and expertise are contextual.*

In accordance with these cognitive themes growing from the learning sciences, integrative STEM (e.g., PD&I) activities are exemplars of constructivist practice in education. They provide a context and framework for organizing abstract understandings of science and mathematics and encourage students to actively construct contextualized knowledge of science and mathematics, thereby promoting recall and learning transfer. Integrative STEM education pedagogy is inherently learner-centered and knowledge-centered (Bransford, Brown, & Cocking, 2000), and when used with groups of learners, provides a remarkably robust environment for the social interaction so critical to the learning process.

Moreover, there is growing evidence that integrative instruction enhances learning. Hartzler (2000) conducted a meta-analysis across 30 individual studies of the effects of integrated instruction on student achievement. Her conclusions included: (1) 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, and (2) integrated curricular programs were successful for teaching science and mathematics across all grade levels and were especially beneficial for students with below-average achievement levels. Similarly, studies of science and/or mathematics taught in the context of design have been shown to improve achievement, interest, motivation, and self-efficacy.

Consistent with Technology Education's General Education Philosophy

The ideology of the field now called technology education has always been grounded in general education (Bonser & Mossman, 1923; ITEA, 1996, 2000; Richards, 1904; Savage & Sterry, 1990; Warner, et al., 1947; Wilber, 1948; Woodward, 1890). Interest in curricular connections with science, mathematics, and engineering dates to the 1870s, when Calvin Woodward—a mathematics professor—began employing manual training methods with mathematics and engineering students. The field's mantra—"technological literacy for all"—clearly reflects its general education philosophy. For these reasons, integrative STEM education, which promotes learning through connections among science, mathematics, technology education, and other general education subjects, is wholly consistent with the ideology of the profession.

The Zeitgeist is Right for Integrative STEM Education

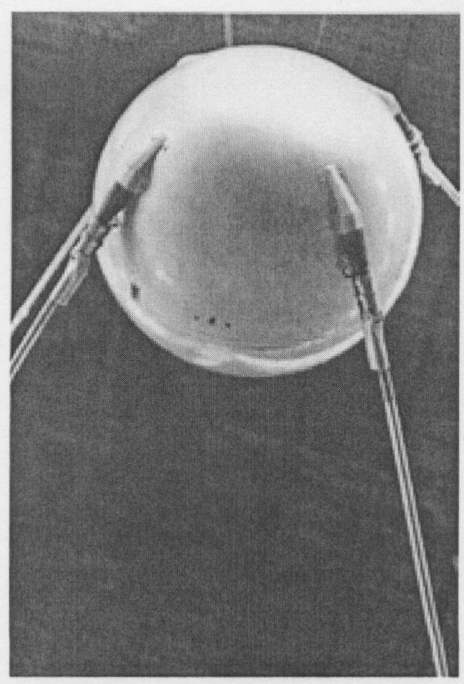
Half a century ago, the launch of Sputnik precipitated major educational reform across all of education. Maley (1959) recognized the opportunity for the profession to be more integrative:

> 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 responded to the opportunity by developing his "Research and Experimentation" course, which situated mathematics and science in the context of technological activity, while most of the field then, as now, focused their energies on redefining itself as a stand-alone discipline, in relative isolation from the rest of education (Herschbach, 1996).

Here we are again. A series of circumstances have once more created an opportunity for technology educators to develop and implement new integrative approaches to STEM education championed by STEM education reform doctrine over the past two decades. Is this opportunity somehow different from the previous opportunities? Is there any reason to believe integrative STEM education practices might emerge in the decades ahead?

Absolutely. First, "technological literacy for all" has begun to resonate widely throughout STEM education. Science education is looking for ways to address their "Science and Technology" standard. In 2009, the *National Assessment of Educational Progress* (NAEP) will begin to assess technological literacy across the U.S. for the first time. The



Sputnik.

National Academy of Engineering (NAE) thought enough of the *Standards for Technological Literacy* content standards to endorse them enthusiastically in the Foreword: "...ITEA has successfully distilled an essential core of knowledge and skills we might wish all K-12 students to acquire." Moreover, NAE produced *"Technically Speaking: Why All Americans Need to Know More about Technology* (Pearson & Young, 2002) and conducted a two-year study that culminated in the publication of *Tech Tally: Approaches to Assessing Technological Literacy* (NAE, 2006). Four years ago, after 111 years of operating, the American Society of Engineering Education established a new K-12 Engineering Division, which passed a resolution two years ago expressing its interest in collaborating with the technology education community in K-12 education.

But far more powerful than these "shared interests" among the STEM education fields is the rapidly emerging awareness in America that technology is not just a ubiquitous component of contemporary culture, but also one of the critical keys to global competitiveness. The publication *The World is Flat* (Friedman, 2005) convinced Americans that the U.S. is losing ground to China and India in the global economy. Friedman pointed squarely at the roles that STEM and STEM education play in the global competition for wealth and power. Corporate America heard the message, and political machinery began to grind. The National Science Board's October 2007 report—*A National Action Plan for Addressing the Critical Needs of the Science, Technology, Engineering, and Mathematics Education System* references "STEM" 20 times as often as it references "science and mathematics" (or "mathematics and science"). Similarly the "America Competes Act" focuses attention on the T and E in STEM, as suggested by its formal title: "America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act." In 2007, the National Governor's Association targeted STEM education for funding. And so on and so forth.

Amidst the realization that the T and E will play a critical role with regard to our welfare in the twenty-first century, the call for support has shifted from "science and mathematics" to "STEM and STEM education." *That's* what is different about the twenty-first century, and that is why integrative STEM education is more compelling today than in decades past.

Relevance to 21st Century Education

Technology education is nonexistent in the K-5 curriculum. The *National Center for Educational Statistics* (NCES, 2008) reports that the average 2005 high school graduate earned only 0.08 technology education credits in high school (compared to 3.67 in mathematics and 3.34 in science). The National Academy of Engineering's Report, *Technically Speaking*, recommended that federal and state educational policymakers "encourage the integration of technology content... *in non-technology subject areas*" [italics added]. The "Science and Technology" standard of the *National Science Education Standards* (NRC, 1996) promotes the teaching of technological design in science class from Grades K-12.

Technology education's future in American education will depend upon its ability to demonstrate relevance to the school curriculum. I believe "technological literacy" will find a home in the twenty-first century school curriculum. The question is: What role will technology education play with regard to "technological literacy for all"? Some believe pre-engineering courses have a bright future in the K-12 curriculum. It's more likely that pre-engineering courses will be perceived as too "vocational" for Grades K-10. Moreover, pre-engineering courses in Grades 11 and 12 add relatively little to American education, simply because most of those enrolling in such courses have already chosen the engineering pathway.

In contrast, "technological literacy" delivered through integrative STEM education offer enormous potential for all students throughout K-12 education. In addition to addressing the "technological literacy for all" challenge, it has the potential to motivate young learners with regard to the STEM subjects as never before and the potential to maintain their interest in STEM subjects throughout the middle and high school years. If so, integrative STEM education would add *enormously* to American education, culture, and global competitiveness. Technology education has a key role to play in integrative STEM education, and could play a significant role in twenty-first century American education if it can demonstrate relevance in this way.

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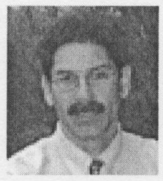

Mark Sanders *is Professor and Program Leader, Technology Education, at Virginia Polytechnic Institute and State University, Blacksburg, VA. He can be reached via email at msanders@vt.edu.*