Introduction

The superiority of a country as a leader in technology is a desired quality. The ability of an educational system to produce individuals with technological abilities is also a desired quality. You are invited to explore the power and promise of a STEM (science, technology, engineering, and mathematics) education through this publication—but more importantly, to seek to understand the importance of ensuring that the "T and E" are equal partners within STEM in order to adequately prepare the next generation workforce and produce valued contributors to our communities and society.

Education should be the cornerstone in terms of helping students to be creative problem solvers while, at the same time, helping to shape their futures. These characteristics are essential to our health, happiness, and safety. Technology and engineering, while being a part of a solid STEM education, create unparalleled experiences to apply technology, innovation, design, and engineering in solving societal problems. Such problems may range from the evolution of new farming equipment to safer drinking water or food to electric vehicles and faster microchips. Students must be able to apply their knowledge to improve people's lives in meaningful ways. As creative problem solvers, students can gain a vision for how something should work and become dedicated to making it better, faster, or more efficient. The latest science, tools, materials, and technology can be used to bring these ideas to life.

STEM education is important if we are to have a society that is to thrive, contribute in a meaningful way towards building our own future, and provide students with a need to achieve. No school subject unleashes the spirit of innovation like technology and engineering education. From research to real-world applications, technology and engineering education consistently helps students discover how to improve human lives by creating bold new solutions, connecting science to life in unexpected, forward-thinking ways. No other area of education can turn so many ideas into realities. Few have such a direction and positive effect on the everyday lives of people. We must count on technology and engineering teachers and their students' imaginations to help us meet the needs of the 21st Century. This area of education is inherently practical, creative, and concerned with human welfare, while at the same being an emotionally satisfying calling.

It is impossible to imagine a life without technology and engineering. Technology and engineering education can start at the earliest grade levels and continue through university experiences to study the grandest skyscrapers, personal transportation vehicles, and microscopic medical devices. It is impossible to imagine a sound comprehensive education without the study of concepts and principles that involve technology, innovation, design, and engineering at the K-12 grade levels.

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Imagine an education based on thoughts that turn ideas into reality, is designed to work wonders, deliver the power "to do," is bolder by design, and can be the next big thing in education. Imagine an education that is called technology and engineering education and imagine that it exists in our schools today and tomorrow.

Despite the obvious need, an education of this nature faces inadequate support at this point in history. It is an old idea whose time MUST come if we are to continue to be a nation of inventors and innovators. We can design education to purposefully create and advance human invention and ingenuity. However, such an education must gain support within and outside of the education community to reach its full potential.

This publication is about an important way of thinking that involves designing and creating in our technological world known as technology and engineering education. Yet, it is an unnoticed, overlooked imperative in the education of ALL students. It is often overlooked by our greatest corporate, political, and educational leaders who value the importance of design, invention, and innovation as key components to a thriving economy and country. As the STEM education movement gains momentum, our leaders cannot continue with the mentality that our society moves forward on mathematics and science alone. It is the technology and engineering component of STEM that unleashes one's capability to create and adapt, using technological problem solving in the resolution of major societal problems. Until leaders start using every component of the STEM subject areas, our educational system will not begin to realize its full potential in creating the next generation of thinkers—with a complete set of skills that will lead us toward new innovations in a way that we have never experienced. Our current "overlooked imperative" must become a "national imperative" for students to reach their full potential as world leaders in STEM knowledge and practice.

We thank and appreciate the many writers, researchers, and practitioners from the STEM community and ITEA membership who have provided the thoughts that are consolidated into this introduction.

Imagine an education based on thoughts that turn ideas into reality...

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Background and History of the STEM Movement

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STEM (Science, Technology, Engineering, and Mathematics) education is currently a hot policy issue that is being touted as a means of maintaining the United States' position of world leadership in technological innovation and undergirding its economic prowess. The rhetoric emphasizes the need for motivating more K-12 students to become scientists, engineers and technicians. What is the history of STEM education and where is it going?

Interest in education involving the study of STEM subjects began in the colonial era when Benjamin Franklin wrote in *Proposals Relating to the Education of Youth in Pennsilvania* [sic] (Franklin, 1749) that topics such as grafting, planting, inoculating, commerce, manufactures, trade, force and effect of engines and machines, and mechanics ought to be taught. Rensselaer Polytechnic Institute was established in 1824 as the first technological university in the English-speaking world to teach the practical arts to the sons and daughters of the tenants on the van Rensselaer feudal landholding. As a result of the Land Grant Act of 1862, agricultural and mechanical institutions were created, with several of them—such as The Ohio State University—developing manual training teacher education as a part of the engineering program in the latter part of the century. As creation and use of technology grew over the intervening years, multiple efforts to institute and teach about technology have been initiated and employed in schools with that history, culminating in today's subject matter in the curriculum. Since the Vocational Education Act of 1917, the federal government has been financially supportive of career and technical education, and more recently the National Science Foundation has been involved in funding innovation and research in STEM education.

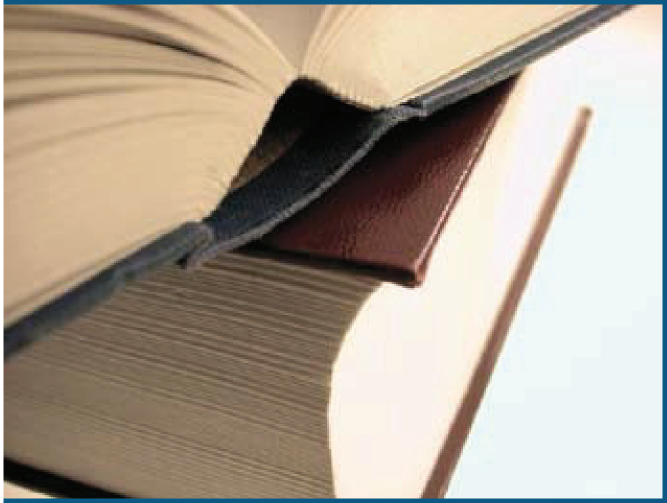
From its beginning in 1950, the National Science Foundation funded education. In the first years, funding was primarily for graduate student fellowships. But, at the urging of Congress, summer institutes for science and mathematics teachers were funded in almost every state by the late 1950s. With the launching of Sputnik, innovative curricula in physics, chemistry, biology, and mathematics were funded, usually to scientists and mathematicians. The Foundation began funding applied research in the early 1960s, but its role was under discussion until 1979 when the Engineering Directorate was established. The Education Directorate was reduced to providing graduate fellowships for about two years in the early 1980s. Spurred by *A Nation at Risk* (National Commission on Excellence in Education, 1983), the Education Directorate was recreated as the Directorate for Science and Engineering Education, and it grew to include the Division of Undergraduate Science, Engineering and Mathematics

Interest in education involving the study of STEM subjects began in the colonial era...

Education (USEME), which funded undergraduate laboratory equipment and courses: A Division of Materials Development, Research and Informal Education, and a Division of Teacher Enhancement and Preparation, among others. In 1991, the Directorate for Science and Engineering Education was reorganized and renamed the Directorate for Education and Human Resources with emphasis on STEM education for ALL, although it was still largely science and mathematics education. The interest in technology education increased, and Congress mandated the Advanced Technological Education program to develop technicians for the high-performance workplace. In the early 2000s, the Assistant Director for Education and Human Resources at NSF coined the acronym STEM for Science, Technology, Engineering, and Mathematics to replace SMET. The Directorate 's emphasis has now moved toward educational research and evaluation to know what works, with whom, and under what circumstances.

In the 1950s and 1960s, the precollege division emphasized disciplinary content and process. The instructional materials emphasized hands-on work and inquiry science. High school science courses in biology, chemistry, earth science, and physics were developed by leading scientists, e.g.: *CHEMStudy*, *Chemical Bond Approach*, *Physical Science Curriculum Study*, and *Earth Science Curriculum Project Investigating the Earth*. The green (environmental), blue (molecular), and yellow (organism) versions of high school biology were created in *Biological Sciences Curriculum Study*. (To find out more about these and other curricula to which we refer, use Google.) Each of these curricula profoundly changed content and pedagogy from the "read about" texts and "cook book" laboratories of the traditional texts. Inquiry was the pedagogy, with students asking questions and doing experiments. These curricula continue to influence the development of materials even today. However, these curricula were to educate students to "fill the pipeline."

Until the 1960s, science for the elementary school consisted largely of teachers telling things to students—if teachers, who were often not comfortable teaching science, included it in the school day at all. Nobel laureate physicist Bob Karplus began doing experiments with elementary school students, and an alphabet soup of curricula were developed including one for students with physical handicaps. One of the



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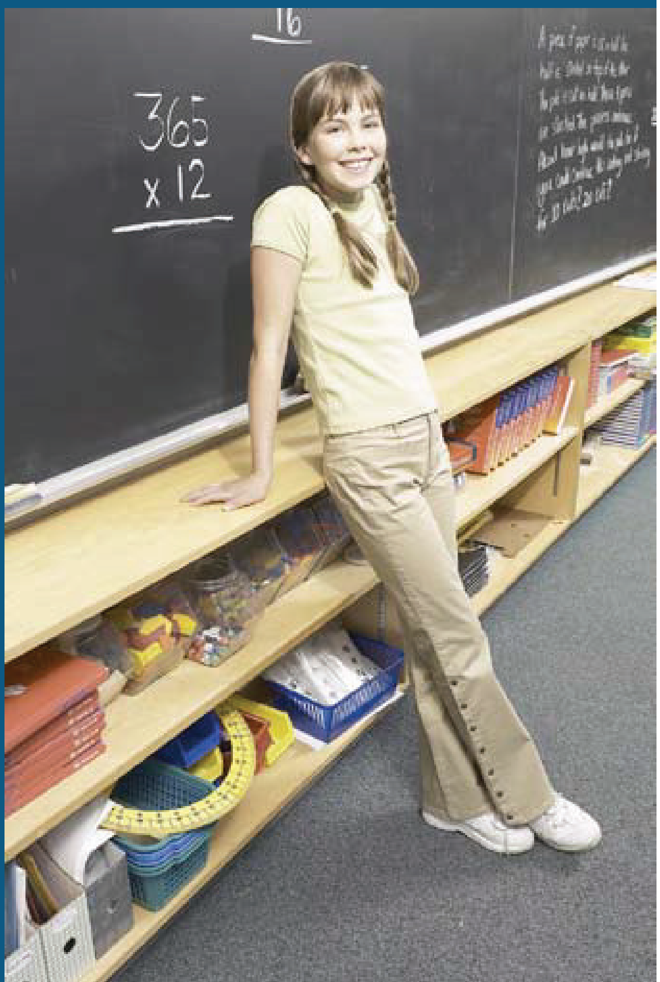

In mathematics education, the reaction to the development of the "New Math" spurred research into mathematics education, especially at the elementary and middle school levels.

elementary school curricula was *Unified Science and Mathematics for Elementary Schools* (USMES), developed at Educational Development Corporation by an MIT engineer and teachers. Students could carry out long-range investigations of real and practical problems based in their local environment. The USMES philosophy centers on the fact that multiple factors contribute to real-world problems. USMES activities are challenges, which may be handled at various levels of accomplishment by students across a wide range of grades. Solutions to such problems often involve overlap between natural sciences, engineering, social sciences, and mathematics. In fact, classes are encouraged to interpret the challenge, narrowing the statement of the problem to a specific one that they are able to operationalize. Students then enumerate the tasks to be done and decide on a specific course of action and delegation of responsibilities.

In mathematics education, the reaction to the development of the "New Math" spurred research into mathematics education, especially at the elementary and middle school levels. These gave rise to *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000) and successful curricula to engage students in learning some of the mathematics in context.

The Man Made World was published in 1971. The chapter titles include Technology and Man, Optimization, Modeling, Systems, Feedback, Stability, Machines and Systems for Men, Logic, and Circuits as Building blocks. The last section of each chapter is called Laboratory and Projects and focused on application and context. The Sloan Foundation funded The New Liberal Arts, which also emphasizes the *Human Made World*. In the 1980s, the Instructional Materials Development program funded a number of projects with a technology and engineering basis for students at all levels, but there was often no place in the schools to teach them.

In the 1990s, NSF funded the development of instructional materials that integrated science, mathematics, and technology. At the middle school, a series of activities such as *TSM Integration Activities* (LaPorte and Sanders, 1993) and a comprehensive curriculum, *Integration Mathematics, Science, and Technology* (IMaST) (Satchwell and Loepp, 2002) were developed. At the elementary school level, *Project UPDATE* (Todd) and *Engineering for*

Children (Hutchinson) provide design experiences for students and professional development for teachers. Several states developed technology education standards and, notably, Massachusetts incorporated technology standards into science standards. Jim LaPorte and Philip Reed (2001) did a study of topics of papers presented at the International Technology Education Association. Prior to 1990 there was about one paper per year on the integration of mathematics, science, and technology. After 1990 the number rose linearly for several years. More recently the number of papers on engineering education appears to have risen dramatically each year.

Project 2061 of the American Association for the Advancement of Science (AAAS) published *Science for All Americans* (Rutherford and Ahlgren, 1991) to answer the question, what should all students know about STEM when they leave high school. This monograph also had sections on technology education, social studies, and mathematics, and not only addressed the content but the habits of mind as well. It was quickly recognized that reaching a goal also needed benchmarks. AAAS developed the *Benchmarks for Science Literacy* (1993) at the same time that the National Research Council developed the *National Science Education Standards* (1995). Fortunately, the two sets of standards, both funded in part by NSF, are reasonably consistent and both include standards for technology. In the 1990s, the International Technology Education Association, with funding from NSF and NASA, developed *Standards for Technological Literacy: Content for the Study of Technology*, (ITEA, 2000/2002/2007), published with a forward from the president of the National Academy of Engineering. The National Academy of Engineering also published reports to encourage the teaching of technology and engineering—*Technically Speaking* (2002)—and on assessment in technology education—*Tech Tally* (2006).

Most recently, the NSF funded a middle school curriculum, *Problem-Based Inquiry Science* and high school science curricula, *Active Physics*, and *Active Chemistry* (all published by Its About Time Publisher) that use design challenges to motivate and assess science learning. The Materials World Modules are enrichment units that use design to teach about materials science and engineering. (Chang, 2009) Other materials developers are increasingly interested in the use of engineering design and real-world contexts to motivate student engagement. However, the recently completed National Academy of Engineering study (National Academies Press, 2009) finds that students take ownership of design experiments and questions in ways that are not engendered by single-answer questions, but in general the materials are very weak on the use of mathematics. When mathematics and science knowledge are related to the technology and engineering content, student learning of content and subject matter is approached in a way that addresses variation in learning styles.

We are beginning to have evidence that one does not become a technician or an engineer from simply studying science and mathematics. In order to achieve that expertise, one has to study technology and engineering, and children do not learn about technical careers without such subject matter in the school. (Cunningham, Lachapelle, & Lindgren-Streicher, 2005). The Museum of Science in Boston is developing *Engineering is Elementary* (Cunningham, 2004-2009) and has embedded engineering design in materials that can be used for both science and language arts for the elementary school.

NSF had a program called Bridges to Engineering Education in which proposals had to be submitted with a letter from both the Dean of Engineering and the Dean of Education at an institution. One outcome was to be some materials, but the real outcome was to be an ongoing viable interaction between the schools of education and engineering to get more engineering in the education of teachers and more education into the engineering programs. Unfortunately, this has not been continued. Engineering schools such as Virginia Tech, Purdue, and Arizona State have departments of engineering education that investigate K-12 education as well. Recently NSF has funded a National Center for Engineering and Technology Education at Utah State University to produce more educational researchers with an appreciation for K-12 engineering and technology education.

At the same time, there continued to be concerns about the place in the curriculum for technology or even integrated activities. The accountability movement stressed language arts and mathematics, with an emphasis on calculation and symbol processing crowding out other ways of learning. Technology education

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activities began to emphasize design, but the designs did not require much understanding of science or use of mathematical analysis. This might be noted as S.T.E.M.—STEM in four silos. The American Society for Engineering Education (which has established an Engineering K12 Center) is one of several organizations that recently became interested in engineering design, which requires more application of science and use of analysis. Also, with the name change from vocational education, career and technical education is taking technical education seriously, and engineering courses have become quite popular.

Twenty-first century skills of teamwork, communications, and leadership are all practiced in the development of a solution to a problem. This is STEM.

There is still confusion about the meaning of STEM education. Some people believe erroneously that technology is really about instructional technologies, but this would put three subjects—science, mathematics and engineering—in parallel with a tool—instructional technology. The preponderance of what is called STEM still focuses on four silos of varying magnitude. In some places, such as Virginia Tech, there is a concerted effort to develop an integrated STEM education program. One could argue that engineering education really is STEM education. Whereas silos emphasize synthesis of disciplinary knowledge to do applications, engineering involves inquiry in the design process to think critically and to solve problems. The principles of science and the analysis of mathematics are applied to technological problems of benefit to society. The learning is in relevant contexts and uses hands-on activities to engage students. Twenty-first century skills of teamwork, communications, and leadership are all practiced in the development of a solution to a problem. This is STEM.

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