Chapter 2: Emergence of STEM Education

The World is Flat?

The world is not really flat, but this phrase has been used many times to describe world globalization. In *The World is Flat: A Brief History of the Twenty-First Century*, Friedman (2005) describes the three distinct eras of globalization: the first dating from 1492 (when Columbus sailed the ocean blue…) until 1800; the second lasting from 1800 to 2000; and the third which is occurring right now…

What happened during these three different periods of globalization? In the first, Friedman describes how the world went from being large to medium sized and claims the motto was, how big and strong are you (as a nation). At that time, being a nation was about muscle, power (horse, wind, steam, etc.), and where one fit into the global schema.

In the second era of globalization, the world changed from medium to small in size. During this era, multinational companies took charge. In the beginning years, the advent of transportation and the Industrial Revolution played a huge role in moving goods and services to a worldwide market. During later years in this era, telecommunication and the early versions of the World Wide Web shrunk the world further and allowed for the “birth and maturation of a global economy” (Friedman, 2005, p. 10).

The question was not, *Where does the nation fits into the world playing field?*, but instead, *Where does a company fit to the newly expanding global market?* These markets were driven by European and American individuals and businesses, but in the current era of globalization, no longer is the world economy driven by western countries, but instead, by wealthy non-Western groups and individuals. The world is now shrinking to a point where
individuals wield power much like countries did in the past. Friedman (2005) describes the “flat-world platform” as:

“...a product of a convergence of the personal computer (which allows every individual suddenly to become the author of his or her own content in digital form) with fiber-cable (which suddenly allowed all those individuals to access more and more digital content around the world for next to nothing) with the rise of workflow software (which enabled individuals all over the world to collaborate on that same digital content from anywhere, regardless of the distances between them)” (pp. 10-11).

This new era is about empowering the individual. To be competitive in this market, individuals need the skills and education equal to their counterparts around the world. The United States was once a superpower and maintains that status currently, but the swiftness of this shift (over the past 14 years) has altered the attention of government officials, legislators, and educators to the need for skills and competencies that will enable America to continue moving forward as a global power. We need to shift our ways of thinking about how to educate our youth from a pre-21st Century model to one that is progressively competitive worldwide.

In the rapidly changing technological world where there has been a fundamental shift in the composition of the workforce, America needed to compete in a global market (Business-Higher Education Forum [BEF], 2002; National Science Board [NSB], 2004; Smalley, 2003; National Science Foundation [NSF], 2005; Friedman, 2005; National Academy of Engineering [NAE], 2005; National Academy of Science [NAS], 2007). Our nation’s well-being depends upon how well we educate our children in science, technology, engineering, and mathematics (STEM) and prepare them for careers within these fields. It is through proficiency in these STEM fields that our economic and national security will maintain our competitiveness in this
Friedman warns that we, as a nation, are currently not preparing our youth for the challenges of the coming global change. In *Rising Above the Gathering Storm* (NAS, 2007), the National Academy of Science warns us of the danger that “…Americans may not know enough about science, technology, or mathematics to contribute significantly to, or fully benefit from, the knowledge-based economy that is already taking shape around us” (p. 121).

The NAS (2007) goes on to detail how our K-12 science and mathematics education, the foundation of our human capital, is failing to prepare students to be competitive with students from other countries. After high school, fewer and fewer US students are pursuing science and engineering degrees. It is estimated that only approximately 6% of American undergraduate students major in engineering, while other countries boast much higher numbers: European countries (12%), Singapore (20%), and China (40%). Other indicators in this report included: (a) the U.S. economy, though strong, has more investments in foreign stocks than in U.S. stocks (remember that this report was prior to the 2008 US financial collapse); (b) the U.S. is sending many jobs overseas; and (c) advanced research in physics (e.g. the particle accelerator) is located outside the U.S. (NAS, 2007)

Much of the focus in this report is on how K-12 education plays an enormous role in the future economy of the U.S. The NAS (2007) recommends that the U.S:

1. Increase America’s talent pool by vastly improving K-12 science and mathematics education.

2. Sustain and strengthen the nation’s traditional commitment to long-term basic research that has the potential to be transformational in order to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life.
3. Make the U.S. the most attractive setting in which to study and preform research so that we can develop, recruit, and retain the best and the brightest students, scientists, and engineers from within the U.S. and throughout the world.

4. Ensure that the United States (a) is the premier place in the world to innovate, (b) invests in downstream activities such as manufacturing and marketing, and (c) creates high-paying jobs based on.

It is their first recommendation that we will focus on in this chapter.

**History of Science Education and how STEM fits in**

On October 4, 1957, the Soviet Union launched Sputnik 1 and rocked the world of science and science education. This small, silver satellite orbited the Earth approximately 1400 times before reentry into the atmosphere on January 4, 1958, 92 days after it was launched (NASA, 2014). The launch of Sputnik reverberated fear throughout the United States and the Race to Space was on. This monumental occasion marked an era that would change how curriculum would be evaluated; particularly with regard to science and mathematics. It was clear to the American public that reform was needed in science and mathematics instruction and education reformers now had an opportunity to shine. Rather quickly, NSF began funding curriculum projects such as the Physical Science Study Committee (PSSC), Earth Science Curriculum Project (ESCP), and Biological Science Curriculum Study (BSCS) (among others) that were developed and taught in schools across the U.S. Mathematics also had its share of curriculum projects, including the School Mathematics Study Group (SMSG), the University of Maryland Mathematics project (UMMaP), and the Madison Project to name a few. With the development of these curriculum projects, teachers had difficulty with implementation as they did not have the content background to support these new reform efforts. Unfortunately, without
content support and professional development, teachers reverted back to teaching content that was familiar to them using familiar pedagogical strategies: not representative of these new approaches to teaching and learning (Bybee, 2013). Technology and engineering were also onboard with curriculum initiatives in the 1970’s with the development of *The Man Made World*, part of the Engineering Concepts Curriculum project (ECCP), but unfortunately, there was no place in schools to teach these concepts (International Technology Education Association [ITEA], 2009).

The 1983 report by the National Commission on Excellence in Education (NCEE), *A Nation at Risk*, revealed a distressing picture of the education system in the United States (NCEE, 1983). Among many things, this report indicated that (a) U.S. students were behind their peers from other developed nations with regard to science and mathematics, (b) many students did not possess “higher order” thinking skills, and (c) the average achievement of high school students was lower than when Sputnik was launched. One of the many recommendations from this report was the development of standards. It was this report that led to the development of *Project 2061-Science for All Americans* (American Association for the Advancement of Science [AAAS], 1989), which provided a framework for K-12 education and established the goal that all Americans must be literate in science, technology, and mathematics by 2061, the year Halley’s comet returns.

*Project 2061: Science for All Americans* led to the development of the *Benchmarks for Science Literacy* (Benchmarks) (AAAS, 1993). The Benchmarks served as a set of coherent learning objectives for K-12 education and a foundation for most state’s science standards. In 1996, the National Research Council (NRC, 1996) released the *National Science Education
Standards (NSES). This was the last attempt at a set of national science standards until very recently.

The national science standards as described in Project 2061 and Benchmarks are not strictly focused on science content as one might expect. Included in these standards are the notions of engineering and technology. Both reform documents include five specific chapters related to STEM areas that are advocated in science education. In The Nature of Mathematics (Ch. 2) and The Mathematic World (Ch. 9), mathematics is described as a “science of patterns and relationships” and an “applied science” (AAAS, 1989, p. 16) and used as a “modeling process” that “plays a key role in almost all human endeavors” (p. 129). The Nature of Technology (Ch. 3) recommends that student have knowledge about the nature of technology as a requirement for scientific literacy (p. 25). The Designed World (Ch. 8), recommends that students have an understanding how technology and human activity shape our environment and our lives. The technologies this chapter focuses on include agriculture, manufacturing, energy sources/use, communication, information processing, and health technology.

It is not only important to know about the concepts of science, technology and mathematics, it is equally important to be able to engage in the practices of these disciplines. In a chapter that brings together these ideas about science and technology practices, Habits of Mind (Ch. 12) outlines the values and attitudes toward science, mathematics and technology. This chapter focuses on thinking skills that are necessary to engage in these disciplines; computation and estimation, manipulation and observation, communication and critical response. Although the acronym STEM was not used in the context of these reform documents, all essential elements of the disciplines were mentioned.

What is STEM?
The term STEM (science, technology, engineering and mathematics) has its original roots in government policy and was coined by the National Science Foundation (NSF) in the early 1990’s. The original term was actually “SMET” (science, math, engineering and technology), but due to its similarity to a vulgar term, a program officer at NSF suggested that STEM be adopted (Saunders, 2009; NAS, 2009). This acronym has been used often throughout the recent history, but the way it is used has been dependent upon the particular situation and users’ context (Bybee, 2007).

STEM is almost philosophical in nature as there really is no operational definition of this concept. Recent research has indicated that even persons who deal with STEM on a daily basis are a bit confused as to its meaning and context. Breiner, Harkness, Johnson, and Koehler (2011) conducted a survey at a major research university in the mid-West and asked faculty members two questions, “What is STEM? And “How does STEM influence and/or impact your life?” They reported that faculty members were able to identify STEM as separate disciplines, e.g. science, technology, engineering and mathematics, but their conceptualization of the term was based solely on their academic discipline. For example, a faculty member who studied biology or worked in medicine might answer the first question with a response such as; STEM as stem cell research or the stem of a plant.

In response to the second question, how does STEM influence and/or impact your life?, it was noted that the faculty responses fell into 3 main categories: societal reasons, personal reasons, and a null (no) relationship to STEM. In the societal reasons category, responses included: “It is life,” and “develops competencies about basic skills used in life.” In the personal reasons category responses included: “I teach math” and “I used a bit of technology and I truly enjoy reading about science.” Some faculty were unaware of the notion of STEM (the null
relationship to STEM category) and their response consisted of not knowing what STEM was or “none that I am aware of.” The most interesting finding under the personal reasons of how STEM influences/impacts your life, and these responses included a faculty member who was disenfranchised about STEM stating, “It further marginalizes my field since I am in the Humanities. It makes my field seem irrelevant, which STEM programs already do. It furthers narrow-minded thinking” (p. 8-9). There has been little further research exploring these questions and, as such, the operational definition of STEM is left up to the parties as to how they will use it for their purposes of argument (Breiner, et al., 2011; Bybee, 2007)

As STEM is made up of four disciplines, one concern from the International Technology Education Association (ITEA) is the perception that the “T” (technology) and “E” (engineering) are oftentimes secondary to the “S” (science) and “M” (math). When we refer to STEM in K-12, it does not mean that students are learning math and science with a little sprinkle of technology and engineering mixed in, but instead it refers to integration of the disciplines. There is often a misperception that technology refers to computers or instructional technology. ITEA advocates that students learn about the development of technology, with a sense toward “the study of all modifications humans have made in their natural environment for their own purposes” and as a disciple that includes the “study and application of learning experiences that relate to inventions, innovations, and changes intended to meet human needs and wants” (ITEA, 2009, p. 22). At least, technology has been an inclusion into the secondary school setting for many years. It cannot be said as much for the inclusion of engineering in K-12 schools.

Engineering has not been adopted into the K-12 setting until very recently, and in only selected schools. Engineering has been strengthened in the K-12 system by the development of technology standards by ITEA. Design is at the core of engineering and often the engineer will
not approach a design unless he/she has a specific human need or want. The engineering design process is an iterative decision-making process that uses the content knowledge of mathematics and science as its foundation (Koehler, Faracas, Giblin, Moss, & Kazourounian, 2013).

Engineering as a discipline in the K-12 setting is often referred to as the missing letter in STEM. Because there are no academic standards for engineering for the K-12 setting, there is no student assessment in engineering education, thus policy makers and school administrators pay little attention to it in K-12 schools (NAE, 2009). This leaves an open opportunity for creative STEM educators to design and implement innovative engineering activities that integrate the STEM disciplines in meaningful learning opportunities for students. It is our advantage that the Next Generation Science Standards (NGSS, 2013) provides several options of how to implement the new national science standards in novel ways throughout grades K through 12, particularly in the field of engineering. In the last section of this chapter, we will discuss NGSS in more detail, and in particular, how it will guide science education in the future.

Federal Funding for STEM Initiatives

The Federal government has been a driving force behind STEM initiatives in the United States. Funding has been plentiful in this area since 2007 when the Bush Administration signed into law the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act, known as America COMPETES Act. The emphasis of this law was “to invest in innovation through research and development, and to improve the competitiveness of the United States” (GPO, 2007, p. 1) and authorized $32.7 billion dollars between FY2008-FY2010 for programs and activities in STEM related disciplines. It also established the creation of a National Science and Technology Summit, a group of Federal agencies, that were tasked to examine pathways for the United States’ STEM initiatives, support
basic research in physical sciences, propose improved instruction in mathematics, increase access for low-income students for AP/IB coursework, and to authorize Teacher Corps programs that would bring 30,000 mathematics and science teachers into the classroom (Bush, 2007).

The Obama Administration reauthorized this Act in 2010 and as part of the reauthorization established an office under the National Science and Technology Council (NSTC) that managed the coordination of STEM education activities in Federal agencies such as the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and the Department of Education (among others). This reauthorized Act described funding resources allocated to these agencies during the FY2011 to FY2013 as well as defines what programs will be funded during this time (GPO, 2010).

Within the 2010 America COMPETES Reauthorization Act, there was a call for the NSTC to create a 5-year federal STEM education strategic plan. In the 2013 progress report, the NSTC outlined five goals to drive Federal investment in STEM education. These goals include:

(1) Improve STEM instruction by preparing 100,000 excellent new K-12 STEM teachers by 2020, and support the existing STEM teacher workforce;

(2) Increase and sustain youth and public engagement in STEM by supporting a 50% increase in the number of U.S. youth who have authentic STEM experiences each year prior to completing in high school;

(3) Enhance STEM experience for undergraduate students by graduating one million additional students with degrees in STEM fields over the next 10 years;
(4) Better serve groups historically under-represented in STEM fields by increasing the number of underrepresented in STEM fields with STEM degrees (including women) over the next 10 years;

(5) Design graduate education for tomorrow’s STEM workforce by providing graduate-trained STEM professionals with basic and applied research expertise to acquire specialized skills in areas of national importance (NSTC, 2013, p. 15).

In another Federal initiative, Race To the Top, President Obama announced a challenge to states to create comprehensive education reform by establishing state-wide strategies to turn around student achievement, adopt rigorous and high-quality student assessments, teacher evaluations and professional development, and data systems to track student performance. This reform was rolled out as a competition among states. This program was funded with $4.35 billion dollars; an unprecedented amount for any education reform initiative. Within this plan, the President advocated what we now know as the Common Core, a common set of rigorous, career ready standards for math and reading. Some of the funds from Race to the Top promoted the adoption of these standards. In the first round competition, two states, Delaware and Tennessee, were awarded Race To the Top funds and a total of 18 states and the District of Columbia have received funds through this program. (USDOE, 2014a)

The future of STEM funding relies on the Federal budget and, as such, based on this five-year strategic plan written by the NSTC, President Obama has proposed to support $170 million dollars for STEM education in the 2015 fiscal year budget. In this projected budget, the President proposed several initiatives designed to improve teaching and learning in STEM subject areas for teachers and students, and to train the next generation of innovators. He also proposed money allocated for STEM innovation networks to support partnerships between school districts and
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universities that would develop streamlined pathways to STEM education and careers. Teacher training is paramount and this 2015 budget includes funding for STEM teacher pathways to recruit and train STEM educators for high-need schools as well as a national program for STEM Master Teacher Corps that will develop teacher leaders who will advocate for STEM education in their communities (USDOE, 2014b). As of the writing of this chapter, the 2015 Federal budget has only been proposed, and given the uncertainty of the Congress, the fate of this funding is anyone’s guess at this time.

NGSS and STEM Education

Funding for STEM initiatives has been plentiful and necessary over the past 7 years, but the question remains, *how does this funding the impact education?* To support these funding initiatives, the standards movement took a turn with the development of a new set of science frameworks, *A Framework for K12 Science Education (Framework)* (NRC, 2012) and a set of accompanying science standards, *Next Generation Science Standards (NGSS)* (NGSS Lead States, 2013) that will guide U.S. science education for the next several years.

While the *Benchmarks* and *NSES* have been the foundation for K-12 science education the past two decades, the release of the aforementioned report, *Rising Above the Gathering Storm* (NAS, 2007), indicated that not much had changed in preparing students for futures in STEM.

Having reviewed trends in the US and abroad, the committee is deeply concerned that the scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength….We fear that the abruptness with which a lead in science and technology can be lost-and the difficulty of recovering a lead once lost, if indeed it can be regained at all (p. 4).
The science education community joined forces and developed a new reform initiative, titled *A Framework for K-12 Science Education (Framework)* (NRC, 2012), to address the need for content in STEM that will drive the K-12 education agenda for the foreseeable future. The format of *Framework* (and later NGSS) is much different than the older reform documents, *Project 2061, Benchmarks,* and *NSES,* as *Framework* outlines three very distinctive areas, or dimensions, that K-12 science education need to focus on for the 21st century learners. These three dimensions include: (a) scientific and engineering practices; (b) crosscutting concepts that unify the study of science and engineering through their common application across fields, and (c) core ideas in four disciplinary areas; (1) physical sciences, (2) life sciences, (3) earth/space sciences, and (4) engineering, technology, and applications of science (NRC, 2012, p. 2).

As the past reform documents focused on scientific literacy, it appears that *Framework* focuses on training a populace that should be STEM literate. In a recent publication, *The Case for STEM Education,* Bybee discusses that STEM education should have a purpose and he refers to aims and goals of STEM literacy; a similar analogy to the notion of scientific literacy advocated by earlier reform documents. In this context, Bybee defines these goals toward STEM literacy for the K-12 setting as:

- “…knowledge, attitudes, and skills to identify questions and problems in life situation, explain the natural and designed world, and draw evidence-based conclusions about STEM related issues;
- understanding the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design;
- awareness of how STEM disciplines shape our material, intellectual and cultural environments;
willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concern and reflective citizen” (p. 5)

Just as Project 2061 is the framework for Benchmarks, so is Framework the foundation for NGSS. You might want to consider NGSS as a road map of student performance expectations that connects areas of practices, content and cross-cutting concepts as they relate to the discipline of science. What makes NGSS so unique is the design of the standards. Each grade level has specific content standards and cross-matched to these standards are science and engineering practices, disciplinary core ideas, and cross-cutting concepts. Teachers and administrators who use this document can easily see how each of the four dimensions weaves together. Most notably in this document is the introduction of science and engineering practices. Teachers may be familiar with the terminology of science practices from the older reform documents, but the new language of NGSS changes the focus of the notion of practices. The language in which we refer is pervasive throughout the document and consists of “modeling,” “engaging in argument from evidence,” and “constructing explanations and designing solutions.” These practices describe how scientists and engineers approach problems and engage in investigations to solve these problems. No longer is the student expected to be the passive learner by “merely learning about (these concepts) secondhand” (NGSS Lead States, 2013, p. xv), but instead they are active learners that are “engaging in scientific investigations that require not only skills, but also knowledge that is specific to each practice” (p. xv). It is our intent with this Road Map Project to foster the development of these practices through the problem/project-based themes that will be described in Chapter 1, and in more details throughout later chapters in this book.

Next Steps in Science Education and STEM
The 21st century learners’ approach to learning must go beyond the traditional ways of dispensing knowledge by passive learning and rote memorization, to one where the teacher becomes a facilitator of activities and a resource to tie together the information being learned. Problem/project based learning (PBL) scenarios are active learning strategies that contextual science, as recommended in the Framework, and are effective in engaging students in the learning. In a PBL scenario, students engage in their lessons by considering “problems as the starting point for gaining new knowledge” (Lambros, 2002, p.1). Although project-based learning and problem-based learning are often used interchangeably, each approaches a situation through a problem scenario but the end result differs. Project-based learning culminates with a produced project whereas problem-based learning results in new knowledge (Capraro & Slough, 2009). Both results are optimal in educational settings that focus on STEM learning as PBL and STEM are often paired as the two contexts that compliment each other. Ideally, the integration of STEM disciplines within PBL allows the learner to holistically approach a real-world problem learning the content and tools necessary to provide its answer.

In this Road Map Project, we utilize PBL scenarios as challenges that are based on the five themes outlined in Chapter 1: Cause & Effect, Innovation & Progress, The Represented World, Sustainable Systems and Human Optimization. We used the content standards from NGSS and aligned these standards to each one of the themes. We divided each grade band, K-2, 3-5, 6-8, and 9-12, into chapters and each chapter will describe how the standards align to each theme. In addition, we provide not only science content standards, but we delve into the Common Core mathematics and language arts standards to support the proposed PBL for that theme.
STEM education goes beyond the silos that are typical in schools today. It provides the opportunity for teachers to integrate not only the disciplines of science, technology, engineering and mathematics, but through the use of a PBL model, teachers can also integrate Common Core standards within the PBL scenario. In essence, it is a win-win situation for both K-12 teachers and students, but most importantly, the students will develop the skills and knowledge that are necessary to engage in further education in STEM fields. This is our opportunity to shine as a nation and the next steps toward global competitiveness. Our time is now! Let’s embrace this moment.
References


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