

**Science, Technology, Engineering, &  
Mathematics (STEM) Education:  
A Reflection on Current Practice**

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## **I. Introduction**

President Obama underscored the importance of STEM education in his speech to the National Academy of Sciences in April 2009, saying that the United States needs to move its students “from the middle to the top of the pack in science and math over the next decade.” He also asked the STEM community to use “love and knowledge of science to spark the same sense of wonder and excitement in a new generation.” In launching the Educate to Innovate campaign in November 2009, he spoke of “strengthening America’s role as the world’s engine of scientific discovery and technological innovation” and declared “the improvement of STEM education over the next decade a national priority.”[Prepare and Inspire pg 7]

Educational initiatives involving Science, Technology, Engineering, and Mathematics (STEM) curriculum are currently being implemented to develop a workforce having more than a strong background in these disciplines. These initiatives aim to develop an entrepreneurial citizenry that will lead the United States in a positive direction or in mathematical jargon – along the “gradient” of increasing financial and educational “scalar fields”.

Results from national and international academic examinations have been instrumental in driving STEM curriculum resurgence and in providing federal educational mandates. Specifically, three instruments, two international assessments, TIMSS and PISA, and one national assessment, NAEP (two varieties – main and long term trend), are referenced when quoting differences in math and science achievement between US students and students of other nations. The long term NAEP assessments show that 12<sup>th</sup> grade academic achievement in mathematics has been stagnant from 1973 to 2009 and US 15 year olds’ international rank in PISA assessment has fallen in both mathematics and science since 2000 [NAEP 2008 Trends in Academic Progress pg 3], [Highlights from PISA 2009, pg 21]. TIMSS assessments have show mixed results since 1995. In mathematics, US 4<sup>th</sup> grade students’ achievement has remained steady while 8<sup>th</sup> grade students’ international rank has improved from 28<sup>th</sup> to 9<sup>th</sup>. In science, TIMSS results show that 4<sup>th</sup> grades students’ international rank has fallen from 3<sup>rd</sup> to 8<sup>th</sup> in this timeframe, while 8<sup>th</sup> grades students’ rankings have improved from 17<sup>th</sup> to 11<sup>th</sup> [Highlights from TIMSS 2007: Mathematics

and Science Achievement of U.S. Fourth- and Eighth-Grade Students in an International Context. pg. 8].

College students in the United States do not pursue degrees in the STEM fields at the same levels as those seen in other nations. The number of Science & Engineering (S&E) bachelor's degrees awarded did reach a new peak of 485,800 in 2007 and the S&E graduate enrollment in the United States also grew to a new peak of almost 600,000 in fall 2006" [Science & Engineering Indicators 2010 pg. 2-4]. However, as reported by the National Science Board, "Currently, the United States produces far fewer STEM graduates compared to non-STEM graduates than most highly industrialized nations. According to the most recent data, 25 percent of undergraduates in the European Union, 47 percent in China, and 38 percent in South Korea chose an Natural Science & Engineering major, compared to only 16 percent of U.S. undergraduates" [Preparing the Next Generation of STEM Innovators: pg. 8].

These educational indicators as well as the state of the United States' economy are currently driving our leaders to insist educators develop new and motivating STEM curriculum to challenge and cultivate top scientific and mathematical talent.

## **II. The Status of STEM**

### **A. National & International Test Scores**

#### **NAEP Assessment Findings**

The National Assessment of Educational Progress (NAEP) was established in 1969 to monitor educational achievement of students in grades 4, 8, and 12 in mathematics, reading, writing, science, and other subjects. The main subject assessments are taken in twelve different subject areas, including math and science, and were first administered in 1969. An additional long-term trend assessment is collected for students of ages 9, 13, and 17 years in mathematics and reading.

#### **Main Assessment 2009**

The results of the 2009 NAEP Main assessment are listed in Table 1.0 and include the following findings: Mathematics: Grade 4 – Student scores have increased from an averaged scaled score of 213 in 1990 to 240 in 2009. This represents a significant increase between these two years,

but the difference between 2003 and 2009 is not significant. Grade 8 - Student scores have increased from an averaged scaled score of 263 in 1990 to 283 in 2009. This represents a significant increase between these two years, but the difference between 2003 and 2009 is not significant. Grade 12 – Student scores have increased from an average scaled score of 150 in 2005 to 153 in 2009. In 2005 and 2009, a new set of assessment frameworks were adopted for 12<sup>th</sup> grade Mathematics and all grade level Science assessment; therefore, there is no basis for a comparison with previous assessments for these data.

Year	NAEP Main Assessment			NAEP Main Assessment		
	Mathematics			Science		
Grade	4th	8th	12th	4th	8th	12th
1990	213	263	294	N/A	N/A	N/A
1992	220	268	299	N/A	N/A	N/A
1996	224	271	304	147	149	150
2000	226	273	301	147	149	146
2003	235	278	N/A	N/A	N/A	N/A
2005	238	279	150	151	149	147
2007	240	281	N/A	N/A	N/A	N/A
2009	240	283	153	150	150	150

**Table 1.0: NAEP Main Assessment Results (Math & Science) 1990-2009**

### **Long Term Trends 2008**

Table 2.0 provides the most recent NAEP Long-Term Trends assessment and includes the following findings: Mathematics : Age 9 – From 1973 to 2008, scores have increased significantly from an averaged scaled score of 219 in 1973 to an averaged scaled score of 243 in 2008. Age 13 – From 1973 to 2008 an increase of 15 points, deemed significant, has been reported (from an averaged scaled score of 266 in 1973 to an averaged scaled score of 281 in 2008). Age 17 – Over the 35 year period from 1973 to 2008, there has been no significant

change in averaged scaled scores (from 304 in 1973 to 306 in 2008). The highest reported averaged score for this age was reported in 1999 and was 308.

Year	NAEP Long-Term Trend Assessment		
	Mathematics		
Age	9 yr	13 yr	17 yr
1973	219	266	304
1978	219	264	300
1982	219	269	298
1986	222	269	302
1990	230	270	305
1992	230	273	307
1994	231	274	306
1996	231	274	307
1999	232	276	308
2004	240	280	306
2008	243	281	306

**Table 2.0: NAEP Long-Term Trends Mathematics 1973-2008**

**Reflections on NAEP Results**

NAEP has a 35 year reporting history and as such provides leaders and educators in all business facets an insight on the performance of students in grades 4-12. From this data, it is difficult to discern many significantly positive trends. Perhaps the greatest trend lies in the 4<sup>th</sup> grade scores in mathematics, which have increased since the first main assessments were taken. The 12<sup>th</sup> grade math and most of the science main assessments have changed formats. NAEP Main

Science assessments are more useful when comparing different regions of the United States or different state results as opposed to a national trend in science. This is unfortunate and would be useful to include in future Long-Term Trend assessment. Currently only math and reading are tested for Long-Term Trends. Long-Term Trends in mathematics show that the United States has been able to increase Gross Domestic Product (GDP) and job growth without a corresponding increase in 12<sup>th</sup> grade student achievement in either math or science. According to Wolfram|Alpha Knowledge Base and the Federal Reserve Bank of St. Louis Economic Data (FRED), since 1970, the United States population has grown from approximately 200 million to 310 million and the GDP value has increased from \$1 trillion to \$15 trillion in 2010. The number of U.S. citizens employed during this timeframe has increased by 86% from 70 million to 130 million persons.

Students in K-12 will soon be taking STEM Literacy exams as part of the NAEP assessment process. “The (National Assessment) Governing Board awarded a contract to WestEd to develop a framework and specifications for assessing technological literacy. In carrying out its work, WestEd collaborated with the Council of Chief State School Officers (CCSSO), ISTE, ITEEA, the Partnership for 21st Century Skills, and the State Educational Technology Directors Association (SETDA). In working with these groups, WestEd used a process for developing the framework and related products that was inclusive, deliberate, and designed to achieve as much broad-based input as possible.” [Technology and Engineering Literacy Framework for the 2014 National Assessment of Educational Progress pg. 1-11].

WestEd, under contract to the National Assessment Governing Board, states, “Because of this growing importance of technology and engineering in the educational landscape, the National Assessment Governing Board decided that an assessment of technological literacy would be an important addition to the National Assessment of Educational Progress (NAEP)” [Technology and Engineering Literacy Framework for the 2014 National Assessment of Educational Progress pg ix]. The first edition of this STEM assessment is slated for 2014. To find out more about NAEP assessments, visit <http://nces.ed.gov/nationsreportcard/>.

## TIMMS Assessment Findings

The **Trends in International Mathematics and Science Study** (TIMSS) is an international assessment of the mathematics and science knowledge of fourth- and eighth-grade (Year 5 and Year 9) students around the world. Since 1995, fourth grade students have raised their averaged scaled score in mathematics from 518 (1995) to 529 (2007), Table 3.0. Of the other 47 countries participating in the mathematics test in 2007, only 6 nations had an averaged scaled score higher than the US 4<sup>th</sup> graders – England, Chinese Taipei, Japan, Russian Federation, Singapore, and Hong Kong. US 8<sup>th</sup> graders as well have raised their scores between 1995 and 2007. In 2007, only 5 (Republic of Korea, Chinese Taipei, Singapore, Hong Kong, and Japan) of the participating 47 countries scored higher than US 8<sup>th</sup> graders. Similar results are found for both the US 4<sup>th</sup> graders and 8<sup>th</sup> graders in the TIMSS science assessments in 2007. Specifically, the US 4<sup>th</sup> graders had an average scaled score of 539 which was bested only by Japan, Hong Kong, Chinese Taipei, and Singapore. US 8<sup>th</sup> graders had an average scale score of 520. Only Singapore, Chinese Taipei, Japan, Republic of Korea, England, Hungary, Czech Republic, and the Russian Federation performed better in the 8<sup>th</sup> grade science assessment. Overall, both 4<sup>th</sup> grade and 8<sup>th</sup> grade TIMSS science scores have been stagnant since 1995. To find out more about TIMSS testing, visit <http://nces.ed.gov/timss/>.

Year	TIMSS Score 4th Grade Math	World Rank 4th Grade Math	TIMSS Score 4th Grade Science	World Rank 4th Grade Science	TIMSS Score 8th Grade Math	World Rank 8th Grade Math	TIMSS Score 8th Grade Science	World Rank 8th Grade Science
1995	545	12	565	3	492	28	513	17
1999	N/A	N/A	N/A	N/A	502	19	515	18
2003	518	12	536	6	504	15	527	9
2007	529	11	539	8	508	9	520	11

**Table 3.0: TIMSS Assessment Results 1995-2007**

## PISA Assessment Findings

The Programme for International Student Assessment (PISA) is an internationally standardized assessment that was jointly developed by participating economies and administered to 15-year-olds in schools. Four assessments have so far been carried out (in 2000, 2003, 2006 and 2009); Table 4.0 provides the results for tests taken.

Since 2000, the United States' international rank for both mathematics and science has trended downward. In 2000, the US rank in math was 18<sup>th</sup> and in science was 14<sup>th</sup>, while in 2009, the US rank in math was 31<sup>st</sup> and in science was 23<sup>rd</sup>. The PISA tests in mathematics and science require students to answer topical questions and explain their analysis and methodology. To find out more about PISA testing visit <http://www.pisa.oecd.org/>.

Year	PISA Score Math	International Rank Math	PISA Score Science	International Rank Science
2000	493	18	499	14
2003	483	24	491	19
2006	474	21	489	18
2009	487	31	502	23

**Table 4.0 PISA International Assessment Results 2000-2009**

When reviewing data from these assessments, one should remember that these are assessments of students in 4<sup>th</sup> Grade (9-10 yrs), 8<sup>th</sup> Grade (13-15 yrs), and 12<sup>th</sup> Grade (17-18 yrs). Though the significant progress seen in math and science scores among US 4<sup>th</sup> and 8<sup>th</sup> grade students is encouraging, the failure to achieve similar growth at 12<sup>th</sup> grade is alarming. Twelfth-grade assessment results along with data relating to undergraduate and graduate degrees in STEM

fields better define the number of students that have the necessary analytical skills and scientific interest that will lead to innovations in STEM related disciplines.

## **B. STEM Majors, Graduates, and Careers**

As an educator, it is not difficult to find the effect that STEM initiatives are already having in the secondary and higher education fields. There exist a variety of curriculum available for high schools and colleges that are being developed by leading STEM companies as a means to attract future employees and inspire future scientists and mathematicians. Academic competitions, scholarship opportunities, and job internships for serious students are common (eg. Worldwide Youth in Science and Engineering, Design the Future (NASA sponsorship), Project Lead the Way, Rube Goldberg Competitions). In fact, there are number of magnet schools that incorporate the title of STEM in their names (Vineyard STEM Magnet School) and offer degrees in Engineering Education or STEM Education Degrees (University of Cincinnati, University of Texas San Antonio, etc.).

The Science and Engineering Indicators 2010 publication provides a wealth of data regarding Science & Engineering (S&E) higher education and S&E employment data both nationally and internationally.

According to this publication, “Higher education in S&E is important, because it produces an educated S&E workforce and an informed citizenry.” [Science & Engineering Indicators 2010 pg 2-7]. In the US, S&E bachelor’s degrees awarded have “risen steadily for the past 15 years” [S&E Indicators 2010 pg 2-4]. Over this same period, the percentage of all students enrolling in S&E baccalaureate programs has remained close to 30%, although the total number of students enrolling in higher education has increased. This means that there has been a proportional increase in S&E baccalaureate program enrollment since the 1990’s.

The National Science Board also claims, “...sustained U.S. S&E workforce growth rests largely on three factors: increased S&E degree production, immigration of scientists and engineers, and few retirements because of the relative youth of the S&E workforce compared to the total U.S. workforce.” [Science & Engineering Indicators 2010 pg 3-6]. Companies and educational

institutions must work harder on retention of persons interested in S&E careers. Specifically, Table 3-2 on page 3-11 of the Science & Engineering Indicators 2010 publication cites that of 16,602,000 individuals with at least one degree (bachelor's and above) in S&E, at most 5,771,000 of these individuals were working in S&E occupations. On a global scale, S&E based industries account for a significant portion of financial output. According to S&E Indicators 2010, "KTI (Knowledge and Technology Intensive) industries...have become a major part of the global economy, providing almost 30% of global economic output" [pg 6-4]. From this statistic alone, developing an educated workforce in S&E fields in future will benefit those countries that highly value competing for global economic market share.

### **C. Economics of STEM/Engineering Education**

Only 6% of the 111<sup>th</sup> and 112<sup>th</sup> US Congresses have and will have degrees in STEM related disciplines. Yet, this group and many other policy makers, recognize that STEM education as an important element to a nation's economy, technology, and defense. Executive and legislative committees and documents establish the need for students to have strong math and science skills. It seems a little hypocritical to require a minority of educators, and technology leaders to raise such a large population of children to have "significant" levels of achievement in STEM disciplines, when they themselves are the one's which typically disliked math and science in their own educational experience. The United States has grown from a nation of approximately 76 million people in 1900 (with a federal debt of approximately \$2 billion) to a nation of approximately 311 million people in 2011 (with a federal debt of approximately \$14.3 trillion). What is however surprising is the fact that politicians, business leaders, and educational leaders have not made overcoming this financial dilemma a priority. NAEP data has been available since 1973 and for the past 40 years has indicated that the academic achievement of the nation's 17 year olds has not improved. NAEP assessments in mathematics last a total of 45 minutes and include both multiple choice and short and extended constructed response questions. This is a very short time period to determine what a person has done in 9 years or 13 years of education.

President George Bush in addressing this financial crisis created a committee – The United States President's Council of Advisors on Science and Technology (PCAST). President Barack Obama has reauthorized its existence since coming into office, through the America Competes

Act. President Obama underscored the importance of STEM education in his speech to the National Academy of Sciences in April 2009, saying that the United States needs to move its students “from the middle to the top of the pack in science and math over the next decade.” He also asked the STEM community to use “love and knowledge of science to spark the same sense of wonder and excitement in a new generation.” [President’s Council of Advisors on Science and Technology pg 7]. Raju and Clayson at Auburn University reflect, “PCAST’s recommendations focus on bettering STEM education across the board; the National Science Board, however, while recognizing that improving overall STEM education is a noble goal and should be pursued, also argues that we should put a greater emphasis on identifying and developing STEM talent” [The Future of STEM Education pg 25]. This provides more information regarding the general disorganization of STEM based curriculum in the United States. However, as the National Academy of Engineering states, “Despite these challenges, it is the committee’s judgment, supported by data gathered during the two years of this project, that much can be gained by working to improve the quality and increase the availability of K–12 engineering education.” [Engineering in K-12 Education, pg. 151].

### **Greater support of STEM/Engineering Opportunities**

The researchers' conclusions suggest that making careers in STEM fields more attractive—through higher salaries, for example—could help employers solve recruiting problems for top talent. Herbst notes, "Highly qualified students may be choosing a non-STEM job because it pays better, offers a more stable professional career, and/or is perceived as less exposed to competition from low-wage economies," [Study: No Shortage of U.S. Engineers pg. 1] This may be a nice idea, but salary alone will not guarantee that an individual stays with an engineering organization. This is especially true if that employee has difficulty with the culture on the job, difficulty with understanding his or her role in the company, and feels that he or she is not making affective contributions or significantly learning more during their tenure.

The Secretary of the United States Navy writes, “In FY 2010, the Navy portfolio included over \$54 million in direct investments as well as an additional \$20 million from the Department of Defense spread across 180 STEM programs nation-wide. An additional \$108 million was invested annually to support domestic graduate students and research assistants under research

grants to academic institutions. These investments are significant but not sufficient.” [Securing Our Future pg. 1].

### **III. Current Efforts to Improve STEM**

#### **Specific Curriculum**

“According to a 2005 Government Accountability Office (GAO) survey of 13 federal civilian agencies, in FY2004 there were 207 federal education programs designed to increase the number of students studying in STEM fields and/or improve the quality of STEM education.<sup>31</sup> About \$2.8 billion was appropriated for these programs that year, and about 71% (\$2 billion) of those funds supported 99 programs in two agencies.” [*Science, Technology, Engineering and Mathematics (STEM) Education*: pg.19] In 2009, the Office of Science and Technology Policy reported, “The 2010 Budget makes a renewed commitment to education in science, technology, engineering, and mathematics (STEM) fields because the progress and prosperity of future generations will depend on what we do now to educate our students. The 2010 Budget invests \$3.7 billion in STEM education programs throughout the federal government in over 100 programs identified by the Academic Competitiveness Council (ACC; see Table), an increase of \$98 million or 2.7 percent over the 2009 enacted level for these programs. In addition, the Recovery Act provides a preliminary \$276 million for these programs, which will be spent over 2009 and 2010.” [*Preparing our Children for the 21<sup>st</sup> Century Economy* pg. 1].

Certainly there are number of STEM related curriculum materials available to educators in the K-12 grade levels. Companies such as Vernier, Texas Instruments, National Instruments, and LEGO have for a number of years provided data collection devices, calculators, and software for use in K-12 science and mathematics classrooms. Science fairs, math and science symposiums, Rube Goldberg machine design competitions, academic competitions such as WYSE or ASM are all regarded as STEM based curriculum/project material. However, the National Academy of Engineering and National Research Council of the National Academies notes, “The committee (has) found no pre-service initiatives that are likely to contribute significantly to the supply of qualified engineering teachers in the near future. Indeed, the “qualifications” for engineering educators at the K–12 level have not even been described. Graduates from a handful of teacher

preparation programs have strong backgrounds in STEM subjects, including engineering, but few if any of them teach engineering classes in K–12 schools.” [Engineering in K-12 Education pg 9].

“The development of students into effective engineering practitioners is a pressing issue for engineering educators. The present study indicates that portfolios can advance this teaching objective.” [Looking Toward the Real World pg345]. More importantly students need to be able to collaborate, construct, and report on engineering/scientific design processes. It is not enough to keep a portfolio if the portfolio contains, in essence, “research papers” without some critical application. This idea of an iterative design, assessment, and redesign, and then presentation is contained in a number of different STEM based curricula and competitions. Not to mention this is the basis of the Scientific Method – Hypothesis, Model, Experiment, Observation, Record Data, Analysis, Reiterate. This is exactly what medical doctors, civil engineers, electrical engineers, and other scientists do prior to releasing a new medication, surgical technique, breaking ground on a new structure, or fabricating a new microwave frequency circuit. Hands-on is the name of the game in STEM if students are to develop confidence with the tools and techniques to create innovative products, design, and test new ideas and models. Certainly research plays a part, but it is not a sufficient ingredient. Research can help to make the iterative process more efficient.

### **Access to Curriculum**

Another problem is, according to Rachel Jones, that “the majority of kids in most school districts in the country do NOT have STEM school options. Instead, in most school districts, science, technology, engineering, and mathematics are included as part of the entire curriculum – not as a specific focus. Many of these STEM subject areas are not integrated into the curriculum or taught on an everyday basis. For example, 29% of K-5 teachers report teaching science two or fewer days per week” [Science, Technology, Engineering, & Mathematics pg. 3]. From a 9-12 grade educator’s standpoint, this is especially frustrating if one works in less wealthy districts. Larger more wealthy districts are able to purchase “relevant” STEM equipment and curriculum and curriculum resources and attend many more STEM competitions than those in smaller, less wealthy districts. Corporate and educational sponsors of STEM education must make access to

these resources as equitably as possible. This is done using low cost simulation software and providing equipment inventory lists, and licensing for curriculum for multiple districts or regional wide.

### **STEM Educators/Curriculum Standards**

The National Science Board suggests, “*the U.S. education system too frequently fails to identify and develop our most talented and motivated students who will become the next generation of innovators*.” Whether this group of students has access to appropriate resources seems to be an accident of birth—whether they are a part of a supportive and knowledgeable family or are residing in a community that has programs and opportunities available to them. There are students in every demographic and in every school district in the United States with enormous potential to become our future STEM leaders and to define the leading edge of scientific discovery and technological innovation.” [Preparing the Next Generation of STEM Innovators pg 5]. It is truly difficult to identify students at a very young age (ie. middle and high school), who may have a significant impact on any particular STEM discipline. It is difficult to predict when and where a particular method of motivation “jump-starts” or “light-turns-on” in a student’s mind. However, many current curriculums and STEM competitions are available for future scientists and engineers to participate in. As the National Science Board reports, “There are many individual successful programs available for talented and motivated students interested in STEM. However, many of the existing opportunities are limited in scope and access, or suffer from a lack of resources. In America, it should be possible, even essential, to elevate the achievement of low-performing at-risk groups while simultaneously lifting the ceiling of achievement for our future innovators.” [Preparing the Next Generation of STEM Innovators pg 16]. One such initiative is the National Youth Science Day (NYSD) activity, sponsored by the National 4-H Council and a variety of universities throughout the US.

NYSD includes a university developed laboratory activity that is capable of being executed by students from elementary to university level. Each national experiment involves inexpensive materials and straightforward instruction sets relating to a current national science research topic. For example, the 2011 NYSD activity involves designing small scale Wind Turbines that generate electricity from natural wind or fans. The turbines are constructed using simple dc

motors, wooden dowel rods, pvc pipe, and a choice of inexpensive materials for the blades. Kits of these materials include a small digital voltmeter and instructions for teachers and students and costs approximately \$22 (including shipping). Students at all levels engage in engineering design projects and experiment with technical equipment that is used by engineers in laboratories throughout the world.

Other successful activities include the Toshiba/ExploraVision Competition. As U.S. House of Representatives member Ralph Hall (Republican-Texas) writes, “The Federal government is investing several billions of dollars on STEM Education activities, primarily at the Department of Education and the National Science Foundation, but also in every agency under this Committee's jurisdiction. However, there are numerous companies, foundations, non-profit organizations, and other groups who are doing their own part, and on their own dime, to successfully promote STEM education and inspire our next generation of scientists, engineers, entrepreneurs, and leaders.

Today's hearing focuses on one of those successful and impressive initiatives, the Toshiba / National Science Teachers Association (NSTA) ExploraVision Competition. This competition is open to students in grades K-12. Students are asked to research any science technology of their choice and explore what that technology will look like in 20 years.” [House Science, Space, and Technology Committee Hearing; "STEM (Science, Technology, Engineering, and Mathematics) Education In Action: Learning Today ... Leading Tomorrow pg. 1]

### **Personal Experience**

Progress enabling products such as those mentioned above in the information fields is built upon the work of a few individuals who decades ago were investigating something called solid state physics—none of whom probably ever thought about CT scans, GPS or iPods—the latter of which can enable one to hold 160,000 books in one's pocket—any more than one today can predict the breakthroughs a half century hence. [Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5 pg. 3]. On a personal note, I remember writing a research paper in high school as a senior for college credit through a local community college and with the help of our school's high school English instructor. The topic that I chose to write about was

the work of three scientists at AT&T's Bell Labs in developing the first point contact transistor. (An aside – my wife's Lennox China is themed – Murray Hill {site in New Jersey of the Bell Lab Building where these scientists worked}). One scientist in particular, John Bardeen, impacted my thinking as a young high school student. I remember a series of Time-Life books, silver, hardback books that I ordered at this time, 1984-85, had a good amount of information regarding computers, their history, and their current application. I, myself, grew up using Timex/Sinclair 1000 and Commodore 64 machines. Since that time, I have benefited from the use a variety of Intel based x86 machines and currently own a Core2 laptop at present. It is difficult to understand the impact that John Bardeen, Walter Brattain, and William Shockley, (Nobel prize winners in 1956 for the invention of the solid state transistor) would have on our society. Inspired as I was, I chose to study engineering – first Civil Engineering at the University of Illinois at Urbana-Champaign, and then Electrical Engineering at Iowa State University. I continue to use and review engineering material as a high school math and physics instructor in Central Illinois.

Although my experience as an engineer in corporate America was short lived, I have come to the realization that great ideas do not necessarily develop nor are they nurtured in a highly competitive environment. I believe that individuals that have access to knowledgeable, experienced scientists/engineers, and instructors that are willing to take the time to answer deep questions are capable of innovative and creative thinking. For example, Thomas Edison, Bill Gates, Steve Jobs, and Dean Kaman, although highly intelligent, innovative, and creative, chose not to pursue the most rigorous course of education that one can achieve (ie. Master's or Doctorate/Post Doctorate of Science in Engineering or other Science discipline), yet they have employed hundreds of thousands of citizens of the United States in a variety of S&E occupations. The companies they developed are currently employing many thousands of US citizens and have made numerous innovations, collected a great number of patents, and have relevant products that are used by individuals worldwide.

## **IV. Difficulties & Barriers in Improving STEM Education**

### **Cultural Hurdles**

Dr. P.K. Raju and Ashley Clayton strike a chord in stating, “Creating a culture that values education is certainly a noble goal, but one that seems quite lofty in a nation where sports figures and pop artists receive million-dollar salaries while educators often start at below \$50,000.” [The Future of STEM Education pg 28] Certainly in the K-12 level, so many students are distracted by the “celebrity” that athletes, musicians, movie stars, and other entertainers have attached to them. This is more than reinforced through the general media and cable television programming and clothing, music cd’s, movie dvd’s and other products advertised to teenage Americans. Part of the difficulty in changing this perception is of course the salaries, but more importantly, teachers at K-12 levels use these products in their classrooms to keep their students “motivated”. The analogy here is that instead of feeding our youth healthy fruits and vegetables that they may or may not enjoy, parents tend to pacify their children with unhealthy foods (ie. candy, sweet treats, etc). Of course many students do use the “celebrity” of athletes to improve their health and competitive nature through sporting clubs; this is fantastic. In fact the academic requirements of states that outline the eligibility of student-athletes are a positive stroke for many students. Just think of similar measures could be introduced in order to make STEM disciplines attractive to students. For example, what would middle school and high school students think if a professional engineer working on the next generation of electric vehicle would allow these students to ride or drive a prototype or a small scale model of this type of vehicle? Also, what if another scientist gave students the opportunity to “build” integrated circuit structures or pneumatic control systems at a national laboratory? What if medical doctors doing research on solving cancer visited with students doing research in similar directions and gave them personal and professional advice and directions for pursuing more information about their studies? These things ARE happening around the US in a variety of schools. Students are attending NASA workshops and flying in planes that simulate low Earth orbit (low gravitational force affects). Students are working with professional engineers to build bridges (balsa wood and manila file folder materials) in academic competitions. Aeronautical engineers are mentoring students in using CAD based tools to design new and more efficient wings for commercial planes. AMAZING!!! However, many students are not able to follow the sophistication of these activities or find themselves with little time left after football or volleyball practice to participate.

Also, students know from siblings or alumni that investing time in athletics and other entertaining enterprises can lead to college scholarships, having a large group of friends/followers or being popular in school. These are attitudes that STEM activities currently compete with and are difficult to overcome. However, there are a few competitions and companies that view these academic competitions as a way to develop innovative STEM employees. Companies such as the Parametric Technology Corporation (PTC), sponsor of the Real World Design Competition, train students in the use of their CAD software, CreoElements, and software simulation modules from other companies (eg. FlowEFD from Mentor Graphics) to design and mathematically analyze wings and other associated aircraft parts. Students performing at very high levels and devoting a good deal of time to these STEM endeavors may find themselves with job offers coming out of high school or college or trade schools.

### **STEM Competitions**

For over 30 years, STEM academic competitions have provided exciting and useful activities for students of all levels to challenge themselves. Since 1950, the Junior Engineering Technical Society (JETS) competition and the Rube Goldberg Machine Design competitions have been a springboard for future engineers and scientists at the high school level. In deed many more STEM opportunities have evolved from these early activities. In addition, the quality and sophistication of computer and software tools that allow for mathematical modeling and simulation have increased dramatically and their costs have allowed public educators to bring this technology to the classroom. STEM academic competitions include many national on-line competitions, such as the Popular Science Young Innovators Design Competition, and the Real World Design Competitions.

### **Mainstreaming STEM Curriculum**

Implementing specific curriculum could result in a “tracking” system or means of “weeding” the best and brightest from high school graduates or possibly providing a “fast-track” employment opportunity for companies sponsoring specific curriculum. This is not a new idea, but on a national scale, the process of attaching STEM curriculum acronyms, similar to the College Board’s AP label, to particular middle/high school curriculum could be used by universities to provide a guide for selecting promising students. The problem with this approach is that school

districts that do not have the means of adopting/purchasing curriculum of this nature would not be able to provide this STEM advantage to its students, even if these students are just as capable and self-motivated as districts that are financially able to provide specific STEM curricula. The American Society for Engineering Education provides a list of currently enacted curriculum being implemented in the United States' PreK-18 educational system, Table 3.0.

<b>Pre-K</b>	
1. Young Scientist Series—Building Structures	Educational Development Center
<b>Elementary School</b>	
2. The Academy of Engineering (also for middle school and high school)	PCS Edventures!
3. Children Designing and Engineering	The College of New Jersey
4. City Technology/Stuff That Works	City College of New York
5. Engineering is Elementary	Boston Museum of Science
6. Full Option Science System	Lawrence Hall of Science
7. Insights (Structures Unit)	Education Development Center
8. Invention, Innovation, and Inquiry	International Technology Education Association
9. A World in Motion	Society for Automotive Engineers
<b>Middle School</b>	
10. Building Math	Boston Museum of Science
11. Design and Discovery	Intel Corporation
12. Gateway to Technology	Project Lead the Way
13. The Infinity Project (Middle School)	Southern Methodist University
14. Learning by Design	Georgia Institute of Technology
15. LEGO® Engineering	Tufts University
16. TECH-Know	Technology Student Association

**Table 3.0: Engineering Curricula offered in the United States PreK-18 Educational System**

17. Technology Education: Learning by Design	Hofstra University
18. A World in Motion	Society for Automotive Engineers
<b>High School</b>	
19. Designing for Tomorrow	Ford Partnership for Advanced Studies
20. DTEACH	University of Texas at Austin
21. Engineering: An Introduction for High School	Arizona State University/CK12 Foundation
22. Engineering by Design	International Technology Education Association
23. Engineering the Future	Boston Museum of Science
24. Engineering Your Future	Gomez, Oakes, Leone/Great Lakes Press
25. Engineers of the Future	(Curriculum based on design and technology courses developed in the United Kingdom)
26. Exploring Design and Engineering	The College of New Jersey
27. The Infinity Project	Southern Methodist University
28. INSPIRES	University of Maryland Baltimore County
29. Introduction to Engineering Design	Project Lead the Way
30. Material World Modules	Northwestern University
31. Principles of Engineering	New York State Dept. of Education/Hofstra
32. What is Engineering?	Johns Hopkins University
33. A World in Motion	Society of Automotive Engineers
<b>Other</b>	
34. TeachEngineering.org	Five-university collaboration (part of the National Science Digital Library)

**Table 3.0 (cont.): Engineering Curricula offered in the United States PreK-18 Educational System**

Each curriculum is different in definition of STEM goals and means of accomplishing these goals. However, many of the underlying aims are the same. For example, “Project Lead the Way (PLTW) has a very organized professional-development effort, which may, in part, explain its rapid growth. PLTW conducts two-week summer institutes, during which prospective PLTW teachers are immersed in the course they plan to teach, including completing all of the hands-on projects. PLTW has agreements with 36 universities to supply engineering faculty who team teach with PLTW master teachers to run the program. According to PLTW, about 7,200 teachers have taken part in the summer training sessions. Teachers who complete the course receive a certificate allowing them to teach the course.” [Engineering in K-12 Education, pg. 105].

In addition, “PLTW is working toward “infusing” its K–12 curriculum into teacher-preparation programs at nine university partners that already serve as sites for PLTW in-service summer institutes. The infusion of PLTW coursework into existing teacher-preparation curricula must be carefully planned to ensure that it aligns with state licensing requirements” [Engineering in K-12 Education, pg. 110].

## **Cost**

“According to a 2005 Government Accountability Office (GAO) survey of 13 federal civilian agencies, in FY2004 there were 207 federal education programs designed to increase the number of students studying in STEM fields and/or improve the quality of STEM education. About \$2.8 billion was appropriated for these programs that year, and about 71% (\$2 billion) of those funds supported 99 programs in two agencies.” [Science, Technology, Engineering and Mathematics (STEM) Education pg. 19]. The two national programs mentioned here by J. Kruezi are the National Science Foundation and the National Institutes of Health. Of course on a much local level, a personal level, a STEM equipment budget of \$2000 can allow a small 9-12 district to participate in three to five different STEM competitions a year as well as invest in “simulation software”, LEGO Robotics equipment, and test and measurement equipment for a small group (eg. 5-10 students).

## **Educating the Educators**

Researchers tend to quote statistics regarding teachers in K-12 schools not having degrees in the discipline in which they are teaching. For example, “Some attribute poor student performance to an inadequate supply of qualified teachers. This appears to be the case with respect to subject-matter knowledge: many U.S. math and science teachers lack an undergraduate major or minor in those fields — as many as half of those teaching in middle school math.” [Science, Technology, Engineering and Mathematics (STEM) Education pg. 1]. This statistic has two other ramifications. One, it speaks volumes with respect to how highly regarded K-12 teaching jobs are regarded with respect to salary, benefits, job conditions (eg. Stress, air conditioning, etc). It is also possible that teachers have more employment experiences and higher levels of attainment in other disciplines other than what they are currently required to teach. The National Science Board’s Science and Engineering Indicators 2010 report recognizes the latter, stating, “Over the past decade, teachers’ pay increased little after adjusting for inflation. Teacher salaries continue to lag behind salaries in comparable professions, and the gaps have widened in recent years.” [Science and Engineering Indicators pg 1-5]. Developing a curriculum does not guarantee that engineering education in K–12 will be successful. A critical factor is whether teachers—from elementary generalists to middle school and high school specialists—understand

basic engineering concepts and are comfortable engaging in, and teaching, engineering design. For this, teachers must either have appropriate background in mathematics, science, and technology, or they must collaborate with teachers who have this background. [Engineering in K-12 Education pg. 71-72]

### **Extraneous Results**

What can the STEM community learn from the educational careers of just a few very famous “entrepreneurs” – Thomas Edison, Bill Gates, Steve Jobs, and Dean Kamen? Three of these most recent men dropped out of university studies to develop economically stimulating products. Microsoft and Apple employ more than 135,000 people worldwide and both companies have produced products that have and continue to affect the business and education of millions more individuals. Edison was a very hard working, ingenious business man that shaped our nation’s society. He had perhaps three months of official education. Edison founded companies that currently employ over 300,000 individuals and have created thousands of patents.

Certainly, these men are “unique” in the manner in which the STEM educational community perceives the process flow of STEM education to work. Students at all levels, K-16 and beyond, are understood to be exposed to STEM curricula ideas and the method of “design” or “problem-based” projects. However, does following a variety of uniform challenges and writing and reflecting on a particular idea guaranty any student that he or she will be successful as STEM entrepreneurs?

Dean Kamen is an inventor, entrepreneur, and tireless advocate for science and technology. His passion and determination to help young people discover the excitement and rewards of science and technology are the cornerstones of *FIRST* (For Inspiration and Recognition of Science and Technology). *FIRST* was founded in 1989 to inspire young people's interest and participation in science and technology. Based in Manchester, NH, the 501 (c) (3) not-for-profit public charity designs accessible, innovative programs that motivate young people to pursue education and career opportunities in science, technology, engineering, and math, while building self-confidence, knowledge, and life skills. [FIRST Website]

## **V. Conclusions, Suggestions & Directions**

### **Conclusions**

STEM education supports the development of research “habits-of-mind” and creativity through specific curriculum assessments and scientific competitions. More than this, leading scientific and engineering educational bodies are interested in US students having an enthusiastic and “entrepreneurial” mind set regarding STEM topics. Many educational research documents purport that STEM education is vital to improving our nation’s economic outlook. These same documents insist that STEM careers and businesses create jobs and improve our nation’s economy by providing products and services that can be exported and stimulate economic growth, including GDP (Gross Domestic Product). Certainly, having a STEM literate citizenry is a healthy and noble goal for any nation and it is difficult to refute the number of inventions and products that the USA has produced over the course of the past 6 decades.

### **Suggestions from Literature & Personal Reflection**

As a dual degree engineer (B.S.C.E {Civil} and B.S.E.E {Electrical}) and having over 9 years of teaching high school math and physics, I feel quite comfortable sponsoring students in a variety of STEM based competitions. Illini Central High School students have participated in the University of Illinois Engineering Open House Rube Goldberg Competition, Bradley University Bridge Design Competition, Illinois Society of Professional Engineers Bridge Competition, WYSE, ICTM, the Real World Design Competition, and ISU CeMaSt math & Science Symposium. Of course I have seen students receive a number of awards and recognition for their participation with these STEM based activities. Perhaps the most important thing that I have witnessed is an alarming “eye-opening” when students realize what they can do with a little fortitude, some guidance, and some creativity. Of course not all students that participate in these activities will pursue degrees in a STEM discipline in college, but I know for certain that they have earned a great amount of self confidence through these events. Confidence of knowing and trying, and willingness to take risks are tantamount to success in these events and in STEM careers as well. I have not had the financial means to adopt a particular STEM curriculum previously mentioned (eg. PLTW); however, I can honestly and with confidence recommend the

following for educators interested in executing successful STEM based curriculum at the 9-12 grade level.

First, I believe students, as well as educators, need to be exposed -- from start to finish – to engineering design projects with an enormous amount of “hands-on” technology time and time devoted to trying new ideas. Specifically, students as well as teachers need to understand and employ elements of the scientific method and engineering design to make an idea reality through sketching ideas (using notebooks), proposing prototypes, constructing these prototypes, testing these constructions, and recreating these products. Much of this framework is available to large, wealthy school districts through curriculum initiatives such as Project Lead The Way (PLTW). Until curriculum like this is equitably distributed to all students, educators should invest time and effort in having students compete in STEM academic competitions such as Rube Goldberg Machine Design Competition, Real World Design Competition, National Youth Science Day, and present at symposiums or science fairs (eg. Illinois State University’s CeMaSt Science & Math Symposium). Many online software tools and competitions can be found through visiting STEM sponsors or technology company websites.

I believe much early work can be done in middle school classes through competitions such as Math Counts and a variety of engineering sponsored bridge and robot task projects and leagues. Companies such as 3-M, PTC, LEGO, National Instruments, Mathematica, and Texas-Instruments that provide STEM equipment such as digital to analog converters, sensors, robotic equipment, calculators, simulation software, CAD software are making the integration of STEM curriculum to K-12 levels possible and should be recognized. Students and educators also need access to professional scientists and engineers to guide or mentor their research and study on a periodic basis. Graduate students or advanced college level students could and currently do participate in activities such as Engineering Open House at the University of Illinois, and Bradley Bridge Pals at Bradley University. This interaction with soon to be professionals and STEM professionals for students in the K-12 is vital. And scholarship opportunities such as those provided by the FIRST organization are important for maintaining student interest in STEM through grades 11-14. STEM comes alive when students form ideas, engineer, and construct their dreams to share and help other with.

Interestingly enough, universities are beginning to adopt STEM degrees. For instance, “in 2006, Colorado State University in Fort Collins established a joint major in engineering and education. To the committee’s knowledge, this is the only program of its kind in the United States. Students in the program must complete general-education requirements, core engineering requirements, engineering-school electives, and professional education requirements. In the first year, 11 students (70 percent of them female) were enrolled in the program. Graduates will receive an engineering degree and a teaching license” [Engineering Education in K-12 pg. 110].

### **Evaluation of these programs**

Do test scores measure work ethic? Do test scores provide jobs, quality of life, and sustaining economies? I do not believe that STEM education is attempting to imply this or another standard. I do believe if students are IMMERSED in genuine STEM education, creative research and innovation can evolve independently of international standards and/or through testing. The following inventors – Bill Gates (Harvard University drop out), Steve Jobs (Reed College dropout), Thomas Edison (three months of official schooling), Michael Faraday (most basic of school educations), Dean Kaman (Worcester Polytechnic Institute drop out; Founder of FIRST (For Inspiration and Recognition of Science and Technology) – Robotics Leagues) provide first class examples of what American Ingenuity represents and at some point in their lives they stepped away from American institutes of education to provide an incredible innovations that we are blest to have. Are these outstanding students or are they creative minds or both? It is my opinion that minds like these do not come along very often, but we need to understand and learn from them. I would not encourage any student to step away from advanced education, but I know in my recent past, I had to step away from an engineering career due to the fact that the companies that I worked for were not satisfying my personal needs for learning or creativity. It is my opinion as well that the evaluation of how successful STEM programs become will be easy to see. Specifically, enrollments and retention rates, and degrees in STEM disciplines will increase. Instead of summers spent on the ball diamond, students will flock to national laboratories or local universities for various “Science/STEM” camps. Technology companies will lead in the creation of jobs and patents. As for the economic destination of the United States, STEM education SHOULD only help our current situation.

## **VI. Summary**

“Two political forces helped stimulate the establishment of mathematics and science secondary schools in the mid-20th century. The first of these was the U.S. desire to stay ahead of its Cold War competitor and the 1950s “space race,” which sparked U.S. efforts to enhance students’ science, technology, engineering and mathematics (STEM) education.” [STEM High Schools pg. 6].

Decades of national deficit spending, rising national debt, and recent increases in the cost of fuel (specifically crude oil), and other commodities, and the growth of national unemployment and national population have pressured political, business, and educational leaders in the United States to find solutions that will bring the U.S. back to its pre-Cold War eminence as a world economic leader and technology innovator. In particular many political leaders fear that, given current economic trends – this “Rising Storm”, the United States will lose its ability to preserve many of the “unalienable rights” citizens of this country currently enjoy. Leading politicians, business leaders, scientists, engineers, and educators are imploring federal and state governments to invest heavily in developing an innovative, entrepreneurial citizenry – a society with competent, scientific analytical skills, foresight, and creativity to create globally competitive businesses and jobs that will provide for a standard of living the United States has become accustomed to during the 20<sup>th</sup> and now the 21<sup>st</sup> century.

I firmly believe that Steve Metz has it right, “How do we encourage more students to consider STEM careers? It is a multilayered problem, but—like most everything in education—it starts with the teacher. An enthusiastic and knowledgeable teacher can become the role model who triggers student interest in STEM and helps students develop the foundational skills needed for careers in these fields.” [Science Teacher pg 6]

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