Catalyzing Fundamental STEM Paradigms in the Accountability Millennium

Robert M. Capraro

Aggie STEM & Texas A&M University

Introduction

Myriad challenges lurk as the millennium continues to mature and our decade comes to a close. The four disciplines of science, technology, mathematics, and engineering (STEM) have been melded into a pronounceable word, not just an acronym. Sometimes STEM is a noun and sometimes an adjective, but in just the right instance, it is used as a verb. I do not argue that what has emerged is what was intended, nor do I suggest that I agree or disagree with how STEM is used. I am simply identifying the trend. As more people move around the globe for education, for economic opportunities, to flee oppression, and for leisure they are choosing to remain where they land regardless of their original purposes for the travel. How do these expats engage with a newfound homeland? How is what they bring valued and by what standards are we as an evolving community held accountable? The reality we face every day as educators, education researchers, and professionals in STEM is that we are accountable for the language we speak whether it is holistic or disciplinary specific or interdisciplinary in nature. Each distinct STEM field builds on, relies on, and inter-reacts with the others, more or less, given some set of conditions, expectations, and potential outcomes. The degree to which those interactions are positive and impactful rests on how well we are prepared to integrate into other cultures, and disciplines, and to accept others into ours.

There are many challenges facing STEM education and its successful implementation, none of which is greater than the ill-informed and self-proclaimed STEM educator or STEM education specialist (cf. White, 2014). When the National Science Foundation (NSF) transformed the arrangement of the starting letters for mathematics, engineering, technology, and science into the ubiquitous STEM, it created a void. Not only did they create a void, but they expressed that the field should then build the meaning. The broadest vision for STEM is that it is a new field, and central to the broader impacts envisaged for the field is the concept of a STEM specialist negating the individual contributions offered by individuals with deep and specific content expertise (Burggren, 2009). In the narrowest vision of STEM, work in any of the four fields counts as STEM. However, researchers continue to question how to best fill this void with a suitable definition and understanding of STEM.

A common compromise among researchers is to integrate any two of the STEM fields into learning, which represents the idea of STEM. As STEM educators, researchers, and professionals, what do we know as a field and how do we know it? What is right? What might be wrong?

What we know from science, is that nature abhors a void. While the void concept works, consider evolution and the work of Darwin – species' voids are filled, unfortunately not always as elegantly as the extinct species that vacated it. Perhaps one of the more prominent void fillers was Homo Sapiens. Many species have gone extinct since our arrival on the scene with about seven new extinctions every 24 hours (Vidal, 2011). We rushed into the ecological landscape and quickly put our thumbprint on all other species and ecosystems on the planet. Since then, humans have become quite comfortable rushing into voids, even when the desire to enter that void is often misguided, unwanted, and premature. That void created by the new term STEM became the destination into which many sprinted. Some transferred from business, some from law, and some from various education disciplines. The influx of non-subject matter specialists was potentially damaging to the STEM education mission. There were no credentials required to proclaim one's expertise in STEM other than to add four simple letters arranged into a now meaningful and pronounceable acronym, "STEM," to one's business card. This confluence of events, the acronym, lack of expertise, and lack of a clear definition and a need to demonstrate STEM prowess gave rise to STEM curricula. Once again, people rushed into the curricula void proclaiming they possessed STEM materials, STEM apps, and STEM software. With one proclamation by NSF, came the progenitors of a new industry, who laid the foundation for STEM schools. STEM schools needed a curriculum, the development of which required people who knew what STEM was and how to "do STEM". The voids were rarely filled by experts but by enterprising business people ready to develop and proclaim their STEM prowess. The question, "Why", might come to mind. Why did the experts wait? Maybe, they were waiting to see how things shaped up or delaying plans for involvement until national agencies had better defined the new "field". The STEM schools came to be hallmarks for schools of choice. When a school of choice claimed to be a STEM school, parents enrolled their children in the alleged school of choice, all the while not really asking how that self-proclaimed school was different from any other school.

The idea of filling voids with STEM generalists is as repugnant as the potential loss of the Humpback whale, the platypus, the bald ibis (kelaynak ~**Ka-lie-nock**), or the mudskipper. The response to filling voids with STEM generalists is to train diverse people in ways that allow them to be aware of, responsible to, and tolerant of curricular diversity where groups of individuals work collaboratively to address integrated STEM needs situated within societal problems.

Each person pursuing a STEM degree beyond the baccalaureate does so with the hope of deepening and enriching his or her knowledge of that subject. If that person persists in higher education, eventually she or he becomes an expert in that particular STEM discipline and earns a terminal degree (i.e., Phd or EdD). It is that terminal degree that signifies that expertise in one very small aspect of a single discipline, and it is the experiences acquired along the way that build co-constructed and integrated STEM knowledge. However, these interdisciplinary experiences are often cursory, and some might argue that they limit individuals to surface-level interdisciplinary STEM proficiency.

For those who pursue higher education, the language of their chosen discipline becomes ever more complex and the words develop very contextualized meaning that only those experts know well. The word integrate has one meaning to sociologists and yet another to mathematicians, and beta has one meaning to a nuclear physicist than say to an evolutionary biologist, statistician, or even a software developer. Words are complex and their meaning is firmly situated within specific disciplines. How can experts in one field really be STEM experts (experts in all)?

How do the ideas of disciplines and voids account for changes in the educational landscape that are influenced by STEM? The answer can be as convoluted as the problem. In fact, some argue that STEM really should be STEAM to include art, or STREAM to include reading and arts. The perfect acronym does not exist. What was NSF really thinking when they dumped this acronym on the U.S., and because of our standing, the world? To include art one might think, well, there is no general aesthetic beauty in science, engineering, technology, or mathematics. Perhaps there simply is just no creativity in any of the them. However, I argue that this mindset is likely the real root of the problem. Those advocating for the infusion of other subjects simplify the experience with science, technology, engineering, and mathematics because all those subjects have their own intrinsic beauty and artistry, the beauty of a new creative bridge design or the first time a computer mouse was imagined, or the simplistic beauty of a succinctly elegant proof in mathematics. Learning to see the creativity and beauty of every subject cannot be achieved by studying the arts; rather, the beauty of the arts is learned by studying the arts. In the same manner, the beauty of any other subject is learned by studying the subject. I flatly reject that arts should be infused because each of the STEM subjects are in and of themselves creative, artistic, and expressive.

What does it mean to be a STEM major, or STEM specialist? Can someone really be a STEM specialist? If STEM exists, how is it different from what was done in the past? Before one can claim to be a STEM specialist it is incumbent to understand where education came from before STEM in order to develop a model that could and should be for STEM.

Imagining a New Definition and Accepting a New Paradigm

First, does "the" problem really exist? Is there really a thing called STEM education? If there is such a thing as STEM, how can it be described so that everyone who sees it knows that it is STEM? How is STEM different from what has always been done? Finally, what are the anticipated outcomes of STEM done well? While the answer is trite – "train diverse people in ways that allow them to be aware of, responsible to, and tolerant of curricular diversity where groups of individuals work collaboratively to address integrated STEM needs situated within societal problems" – it is not simplistic in implementation. This is the second time I offer this definition in the hope that one day it will be embraced. This definition requires new and expanding collaboration, diversity, and dedication to change, or we are constrained to doing what has always been done and reaping the same outcomes we have historically seen.

Using ideas from broad contexts across disciplines that are explored through multiple lenses can provide insights into problems that would otherwise go unexplored or seemingly unanswered. What we learn from the multiplicative identity property is that the number of problems multiplied by one person exploring the problem results in the exact same number of problems. But the nature of STEM work necessitates that individuals be able to explore more problems effectively, so we need to think about another property of multiplication that can afford greater diversity in approaches and solutions. The commutative property is one that can be made analogous to developing partnerships to solve problems, that is, multiple people working on multiple problems resulting in potentially more solutions regardless of where we start, either with the number of problems or the number of people. The importance here is that while we have a fixed approach, the product or the solutions are greater than the identity condition given the same sample set. For example, using the identity property, if we had eight problems, we might have eight solutions at the end (8×1) because one person will develop exactly one solution per problem. At best, we might actually find eight solutions. However, from the commutative property, if we start with eight problems and now have two people, the potential solutions increase to 16. Multiple views and multiple backgrounds facilitate the diversity of approaches to problems and can yield very different admissible solutions that also might make use of some very creative and unique options.

Where to Start

The idea of STEM has to start somewhere; and its origin is foundationally rooted in my primary field, mathematics. This story is inextricably interwoven with politics, mass media, business, and economics, my personal economy and the economies of countries.

Mathematics is fundamentally a conflicted field. The study of mathematics can be personally viewed as either a process of creation or discovery. Mathematics is either discovered and has always existed, waiting for someone to stumble across it, or it is created by individuals or groups of individuals to meet societal needs. The implications of ones' beliefs are neither trivial nor rudimentary -- for in one's own fundamental beliefs about mathematics lies one's own life outlook and one's understanding of the concept of STEM, in general.

Discovery

For example, mathematics as a process of discovery allows for exact mathematical models, precise calculations, and most importantly, the ability to predict how the world works. Take, for example, Professor Peter Higgs. He used mathematics and mathematical modeling to predict the Higgs boson particle – also named the "god" particle. This particle was theorized to be responsible for giving other particles mass.

His theory was predicted through a mathematical model in 1964. The technology did not exist to substantiate the model or test the theory until 2012 when the European Organization for Nuclear Research, or CERN, found evidence to support the existence of the Higgs boson particle. In 2013, further experimentation found that the particle has two important properties that professor Higgs predicted: 1) + parity and 2) zero spin. This shows that mathematically precise models can characterize our natural world well ahead of being able to demonstrate it.

Creation

Another view of mathematics is that of creation. Our mathematics is created to suit our own particular view of the natural world and is as fallible as our collective view of that world. In fact, Eugene Wigner described "The Unreasonable Effectiveness of Mathematics in the Natural Sciences", and Albert Einstein said, "The most incomprehensible thing about the universe is that it is comprehensible" because mathematics provides the framework. We create the mathematics to fit our perspectives of the natural world. Ada Lovelace created an algorithm for calculating a sequence of Bernoulli numbers, now acknowledged as the world's first computer program; Euclid created planar geometry given some very specific assumptions; Isaac Newton and Gottfried Leibniz created calculus; and ibn al-Haytham created algorithms that support rigorous experimental methods for controlled scientific testing that substantiate inductive conjectures. Mathematical models can be created to predict how infectious diseases progress, to show the likely outcome of an epidemic, and to help inform public health interventions.

These created models use some basic assumptions and mathematics to find vectors for various infectious diseases and use those parameters to calculate the effects of possible interventions, like mass vaccination programs or the survivability of a population without vaccination. They can predict whether the spread of a disease is endemic or epidemic.

The Real Problem

The medical community was taken completely unaware by the Ebola outbreak of 1976 in Zaire, and more recently, by being unable to prepare for the Zika Virus. The Zika virus surprise makes it difficult to determine its likely outcome vector or its potential impact on human reproductive success. Given our view of the natural world, we are still unable to predict the stock market, develop a sustainable economic model, or model disease etiologies. Therefore, there must be something fallible in the way we view or interpret the natural world and the mathematics we create to model it. So, there must be an element of creation and discovery that has yet to occur. For example, the non-computability of the probability of consequential, but rare, events (this means very very important) using scientific methods has been explained in the Black Swan theory. It lies in our lack of understanding of the natural world and inability to model unknown unknowns. This is a field where likely new mathematical discoveries and creation will occur.

For those listening for the NEXUS, as you noticed in my examples so far, mathematics is the tool by which we interpret, describe, and interact with the natural world around us. Our paradigms and practice intersect to determine the value of the education we receive and the value we place on sufficiently flexible knowledge that facilitates our ability to answer questions we have never before conceived. If we continue to have experts working in silos with others with the exact same training and preparation, we will stagnate and fail to answer many of the emerging important questions of the new millennium. So, what model of mathematics do you think we really need, discovery or creation?

Has anyone suggested that irrational numbers were not created but discovered by Hippassus of Metapontum, and that pi was discovered by measuring the circumference of circles and dividing by the diameter? No matter the size of the circle the ratio was consistent; this result seemingly fits with discovery. However, other ideas have been invented to account for the natural world. For example, Lobachevsky created non-Euclidean geometry by simply making a different assumption that seemed to fit with his version of the world.

While the creation or discovery debate could go on forever, the point is that each form of mathematics, like the other subjects, is complex and is comprised of various aspects of discovery and creation. The importance is that no mathematics would ever have needed to be created without other subjects. Newton, Lobachevsky, Einstein, and others were all motivated to create mathematics to model the science, technology, and engineering of the world. Regardless of your own personal position exploring the NEXUS of discovery and creation, the solutions to the challenges of tomorrow lie in mathematics.

The Nexus of STEM Subjects

So, when is a good model, good enough? When is mathematical estimation sufficient and the difference between the calculation and estimation trivial. For example, the formula for pooled standard deviation is $SD_{pooled} = \sqrt{}(X_1-\bar{X}_1+X_2-\bar{X}_2\ )/(N_1+N_2)$. This is the nexus of creation and discovery. However, the easy version of this formula is $SD_{pooled\ EZ}=(SD_1-SD_2)/2$. Which one is the better choice? Which one should we use? Can you justify your answer? How you answer reveals your personal view of discovery or creation. More importantly, your choice to use one formula might reveal whether you are more a mathematician or statistician (see Table 1).

The full formula requires a bit of work, whereas the approximation requires very little. As you can see, we have an exact mathematical equation for pooled standard deviation, but does an approximation formula function just as well? Even when the standard deviations are quite different both formulas work reasonably well.

These formulas work well when the groups sizes are similar, but when one group size varies greatly from the other and the standard deviations are very different, the EZ formula can eventually give erroneous results. So, the important question is, what are you going to use the pooled standard deviation for? The more consequential the decision, the more precise you need to be, and the more you understand when and how the formulas work, the more autonomy you have to decide what to use and when.

For a more scientific bent on the idea of invention and creativity, let us consider the space race. Now for a prominent scientific event, consider the U.S. trip to Mars as a mathematical model. A National Aeronautics and Space Administration (NASA) engineer was quoted as saying, “For convenience. . . We consider a simplified conceptual model that omits details that are likely to have only a minor impact on the outcome.

We assume that there are no forces other than gravity, that there are no changes in flight conditions, and that the launch is successful if and only if the launch protocol succeeds in giving the ship enough momentum to escape the planet’s gravity and safely embark on the space voyage”.

For engineering purposes, mathematics was used to provide “good enough” solutions, and some terms in an equation were ignored because they were hypothesized to have only minor impact. The reality is that the model worked, and the ship landed on Mars and returned to Earth.

Table 1. A Comparison of the Two Formulas

Statistics	Participant	Treatment	Control
	1	40	55
	2	50	60
	3	60	65
	4	70	70
	5	80	75
	6	90	80
Mean		65	67.5
SD		18.708	9.354
SD_{pooled}	14.790		
$SD_{pooledEZ}$	14.031		

Therefore, building on an Engineering Design model has the greatest potential to develop the type of thinkers we require, those equipped with the competence and confidence to question the mathematics and science they were taught and to challenge the establishment to prove themselves correct.

Engineering design is the creative application of science and mathematics to solve problems. The truest intent of education, whether we consider the Ottoman Empire, Roman Empire, or Greek Empire, is in the equity of its availability to the lowliest of citizens.

The Ottoman Empire, arguably the more recent, was also likely the most democratic in education policy. An in the Ottoman Empire, arguably the most democratic access to science and mathematics was achieved. It is through true democratic access to a high-quality education that we will nurture the next Brahmagupta (around 650 AD), Al-Khowarizmi (879 AD), Purkinje (1823), Tesla (1900), or Higgs.

STEM Movement and Its Impact on Employment

In the news lately, there has been discussion about liberal arts majors struggling in the job market. In fact, at a conference in 2013, Mark Andreesen, from Venture Capitalist, told the crowd that the average English major is likely to end up working at a shoe store. A McKensey study found that liberal arts majors have higher rates of unemployment, more debt, and are less happy with their jobs. Compare their situation to that of engineers, who are in such demand that tech leaders are lobbying intensely for the increased immigration of skilled individuals in STEM, in part due to the inability of United States universities to produce enough STEM graduates to supply the STEM job market.

Although mathematics and engineering backgrounds might help get a job, they are no guarantee of success. In The Wall Street Journal, Aetna CEO Mark Bertolini, who has a mathematics and accounting background, said, technical skills are “necessary but not sufficient”. College graduates need to be able to solve problems in complex settings where the outcome is often clear and explicit while the human quandary for selecting among possible solution strategies is messy, unspecified, and in the most natural world, a human experience without a readily available solution.

It is paramount that corporations and business professionals, politicians, STEM professionals, pre-collegiate and collegiate educators, and administrators collaboratively engage with current academic, political and business challenges to prepare a citizenry capable of understanding challenges we do not yet comprehend so that they might provide the answers to the most perplexing challenges we are bound to face. It is important to understand that the mathematics we know and force upon students today may one day be considered completely inadequate and our unwavering dogmatic worship of it to have been among our greatest collective global foibles.

Higher Education and Its Responsibilities

Higher education institutions in which businessmen and women, politicians, and STEM disciplinary professionals are prepared must be reengaged around important global problems. It is only through this integrated learning that procuring solutions is likely. An immediate problem is that of global climate change. One might think the issue global climate change to be trivial; some may consider it to have been blown out of proportion and facts exaggerated to give way to political rhetoric and scholarly band-standing. It has never been more true than for the facts to be negotiable and beliefs to be rock solid. Politicians needing a platform champion one view or another without regard for facts but public opinion, business leaders take a stance favoring their profits, and climatologists and other STEM professionals struggle to build reputations that will be aligned with continued funding to support their work. All these stakeholders would benefit from greater interdisciplinary knowledge and understandings. The climate is what is, most agree that we cannot change whatever will happen. In fact, the Earth has experienced major global climate events in its history that had nothing to do with human intervention.

For example, it was likely major global climate events that changed the course of evolution on the earth (Cambrian Event and the Ordovician ordeal, to name just two). Another hot topic for political rhetoric and corporate grand-standing is that of fossil fuels versus renewable energy. The Fossil fuel debate is one we can ill afford to neglect and argue over. Fossil fuels are nearing their foreseeable exhaustion. Globally, crude oil prices are hovering around their 10-year low, while prices per liter of fuel are near an all-time high.

Creating solutions to these issues necessitates qualified individuals who have a comprehensive and interdisciplinary STEM knowledge that will equip them to develop innovative strategies and solutions. High-quality integrated STEM education can only come from clearly articulated definitions, goals, and objectives, which are the only way to design an aligned curricula. To address the issues related to profit from STEM, businesses and media outlets must join with education to build stronger programs that move students into both traditional STEM jobs and those of the "hidden" STEM workforce, technology and manufacturing careers that require highly specialized STEM knowledge but not a four-year degree.

What Universities Can Do

The primary problem universities must be prepared to address is the renewable power grid. Developing silos of renewable energy is not a national response and certainly will not ensure global access. However, economic power and new empires will rise depending on the response to a global renewable energy grid. It is up to teachers to foster interest and build intrigue around interesting and noteworthy problems. They must spark the creative interest in STEM that will sustain students in the STEM pipeline. While it is teachers who shoulder the greatest responsibility for building tomorrow's greatest thinkers and innovators, it is the university who has the responsibility of preparing those teachers and providing ongoing, systematic, and sustained professional development for those already working in schools. It is not important that every university develop centers of STEM excellence; however, it is essential for universities to collaborate both within and across institutions.

Before we can expect universities to collaborate, the faculties of business, education, engineering, science, mathematics, and technology must learn to collaborate and to build knowledge across those disciplines. It can be much harder for a university to change their practice, so centers of STEM excellence like BAUSTEM at Bahcesehir University and Aggie STEM at Texas A&M need to collaborate to ensure that faculty receive information, generate ideas, and develop research-based rationales for metastasizing their instructional strategies across disciplines and within their colleges. They must recognize that highly engaging and dogmatically focused instruction centralized around large societal themes and issues are going to be required. Unfortunately, this "wicked problem" is unlikely to be resolved without a systematic approach with many engaged stakeholders; international discussions about STEM must result in a definition suitable for addressing global issues. Unless young children are challenged, they will not be ready for re-envisioned university instruction. Change must be approached in small increments with persistence in a global reform effort. Young children should begin this process by experiencing classroom instruction rich in understanding of societal problems that first pertain to their home, classroom, schools, and neighborhoods. As they get older, their societal views should expand to include their cities, municipalities, region, country, and world. Once they enter college, they will be capable of considering global needs as they learn challenging integrated college content. It is likely that the renewable power grid problem will be addressed within universities before it ever gets addressed politically or industrially.

Accountability and Time Wasted on Testing

One insidious barrier to global change in education is teacher accountability and mandatory testing. Accountability is an interesting idea. It is not practical nor is it particularly interesting from a quizzical and motivated standpoint. It is more appropriately “interesting” in the sense of I have nothing really nice to say, so I am using the word interesting so most people will not recognize it as being laden with disdain and condemnation. We must re-envision the idea that accountability is the way to achieve economic prosperity. Teaching is not dentistry. If a patient comes in with a cavity, the dentist drills out the rotten part of the tooth and fills the void with a durable material. Simple. The dentist is not held accountable for the underlying causes that precipitated the tooth decay. Why are teachers held accountable for the myriad social, psychological, and medical mediators to learning? Education is not as simple as dentistry - there are many ancillary issues surrounding how and under what circumstances children learn. Teachers can teach and teach well, but some students still will not learn as fast or to the same degree as other students.

While parents continue to care about high stakes exams and companies make fortunes perpetuating parent’s fears while propagating myths about teachers’ lack of content knowledge, underachieving schools, and poorly trained teachers, we continue to expect more from teachers with less investment. National and multinational companies will continue to prosper by selling the promises of success but failing to deliver success for all. Rhetoric will continue from officials looking for reelection to companies trying to convince state boards of education, school districts, and parents that they have the children’s best interest at heart.

Businesses sell the idea globally in every language where people have the money to purchase it; “use our materials for STEM instruction and our tests to make sure the teachers are really teaching your children”. All this salesmanship and the research is univocal; no STEM curriculum has been shown to be more effective than a traditional curriculum, and NSF funded curricula are only marginally better in some very specific instances. The many justifications for and supposed benefit of accountability have left parents misinformed, and those with the knowledge and authority to do so are reluctant to set the record straight. When politicians indicate that a test can measure learning from one year to the next or that a company can develop a test that can assess if a teacher has done his or her job, they are simply misinformed at best and conspiring to cheat you at worst. From decades of brain research in the disciplines of neuroscience and psychology, we know that people learn differently and at different rates. The idea that any test can evaluate if a child learned one-year's worth of content is a lie wrapped up in fear that is propagated to make parents feel better when their child scores high and loathing when their child scores low. Accountability in its current form should be reconfigured and instead used to determine what a child can do compared to other children nationally and internationally. Tests should be comprehensive and meaningful. Their use should give as much of a "benchmarking" of one child's knowledge as it does to understanding what the child needs to learn the following year. Unfortunately, the curricula each year is not predicated on students' existing knowledge; the level of conceptual understanding and skills a child acquires one year has no relation or influence on what he or she will be required to learn the following year. This system underscores a costly error in judgement in education by those charged with making such decisions. The push to have accountability has been at the expense of equity and social justice. Those who know more continue to learn faster and those who are struggling will continue to struggle with ever widening deficits. For these reasons, each time I hear the word accountability, I understand "education for the rich and powerful."

In conclusion, I look back in history to find someone ahead of his time, an inducted a quote from Albert Einstein who was talking broadly, so much so, that I have inducted his sentiments to truly reflect STEM, had that concept been created in his time:

> Powerful STEM integration, ". . . can only be created by those who are thoroughly imbued with the aspiration towards truth and understanding. This source of feeling, however, springs from religion. To this there also belongs the faith in the possibility that the regulations valid for the world of existence are rational, that is, comprehensible to reason. I cannot imagine a scientist without that profound faith. This situation may be expressed by an image: science without religion is lame, religion without science is blind." (Albert Einstien, 1936).

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