RESEARCH HIGHLIGHTS IN STEM EDUCATION

Editors

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SECTION 1
SPELLING STEM

Defining the 'S' in STEM: Nature of Science as a Component of STEM Literacy

Valarie AKERSON
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How did We Get to "STEM?"

It seems we have a new acronym "STEM," which is sometimes even "STEAM" (just add "art") or "STIM" (just add "informatics") depending on what the individual letters stand for and who is using the term. Typically "STEM" stands for Science, Technology, Engineering, and Mathematics. But why do we have this new acronym, and what does it really mean? Bybee (2013) states that the meaning is ambiguous and could even be considered political. It could even be seen as a buzzword to gain attention and funding. Instead of stating that their work is in science, technology, engineering, or technology education, researchers could state they have a "STEM" project, which could gain attention and possibly more funding as it connects to the newest buzzword. How can we make "STEM" (or any of its variations) more than a buzzword? How can we include all the components of STEM in education, in an integrated and meaningful fashion? Is STEM just a slogan, or can it be a meaningful way of education?

My own perspective is from that of a science educator, trained as a science educator. In my work I help prepare preservice elementary teachers to teach science. And yet, it seems that I am now I am also supposed to be preparing them to teach STEM. Yet, what is STEM? Is it "simply" science, technology, engineering, and mathematics? Or is it bigger than that?

First—Scientific Literacy

Whatever your definition of STEM, one thing is common—we all agree on the goal for a scientifically literate public (NSTA, 1982), even if we don't exactly agree on the same definition of "Scientific Literacy."

What is clear is that "simply" understanding science content is not enough for scientific literacy. Knowing scientific laws and theories, as well as concepts that are found in all the science textbooks is not enough to be considered scientifically literate. Knowing how that knowledge has developed through scientific "practices" is also not enough. People need to actually be able to use the scientific knowledge to help them make informed decisions about issues that affect them, their lives, and their world. Unless individuals understand science as a way of knowing, in addition to the content and practices, then they would not be able to use the knowledge to make informed decisions, and therefore would not be considered scientifically literate. Lederman and Lederman (2014) share their idea that science can be thought of in at least three interrelated parts: (a) science as a body of knowledge—the content part of science, the science that you read in textbooks, (b) strategies for developing scientific knowledge—the methods of science, the practices of science, and (c) characteristics of the knowledge itself—the very nature of scientific knowledge (NOS).

Knowing how scientific knowledge is developed, and the characteristics of that knowledge, is essential to making informed decisions. Without being able to weigh claims made by scientists, and understanding the strengths and even weaknesses of that scientific knowledge, people will not be able to make informed decisions about issues in society. Therefore it is essential that the general public have an accurate understanding of the very nature of science itself.

In the United States we now have the Next Generation Science Standards (NGSS) (2013). These Standards now also incorporate not only science content and scientific practices, but also engineering practices, that teachers K-12 are responsible for teaching. Unfortunately, with the exception of a few secondary science teachers, most public and private school teachers never take even a single engineering course, and likely have very little understanding of engineering itself. Not only that, but most university science and mathematics educators, who are responsible for preparing science teachers, also have never taken an engineering course, and therefore also have limited understanding of engineering, which limits the connections that can be drawn and interwoven among the components of science, technology, engineering, and mathematics—STEM.

Despite the lack of formal engineering coursework, K-12 teachers are responsible for teaching science across the three dimensions included in the NGSS. These dimensions are the Disciplinary Core Ideas, the Science and Engineering Practices, and the Cross-Cutting Concepts. The Disciplinary Core Ideas are basically the content of science—the knowledge that has been developed about science—the content found within the science textbooks. The Science and Engineering Practices include conceptualizing how scientific and engineering knowledge is developed—the methods used by scientists and engineers in developing knowledge. The Cross-Cutting Concepts include ideas that transcend all science content, and are considered then, as part of science. It is within the Science and Engineering Practices and the Cross-Cutting Concepts that we find ideas about NOS and scientific inquiry. In the next section we look into the specific aspects of NOS that are present in the Science and Engineering Practices as well as the Cross Cutting Concepts. We then turn our attention now to research on NOS and scientific inquiry.

Nature of Science

The Next Generation Science Standards contain ideas about Nature of Science (NOS) that need to be included in K-12 in science lessons. Within the Science and Engineering Practices section there are four aspects of NOS to be found that K-12 students should know by the end of high school. First, scientific investigations use a variety of methods. One can still often times see a poster of the steps of "The Scientific Method" posted on a classroom wall, when in reality scientists do not use one simple method. In fact, many investigations are descriptive and/or correlational, and simply do not fit "the scientific method." Second, scientific knowledge is based on empirical evidence. For something to be a scientific way of knowing, there needs to exist empirical data that supports the idea. All scientific knowledge is at least partially based on observations of the natural world. In addition, all theories and laws can be checked against what actually occurs in the natural world, which will substantiate the scientific knowledge, as well as allow for predictions. Third, scientific knowledge, though robust, is open to revision in light of new evidence. If new evidence is found, the scientific knowledge can be changed or modified. Similarly, reinterpreting existing scientific knowledge can also allow for changes in scientific knowledge. Fourth, scientific models, laws, mechanisms, and theories, explain natural phenomena. These are different types of scientific knowledge, but all help explain phenomena and all arise from interpretation of empirical evidence. Laws describe relationships among observable phenomena and theories are inferred explanations for observable phenomena.

There are also four aspects of NOS to be found within the Cross-Cutting Concepts section that students K-12 should conceptualize. The first is that science is a way of knowing, that is different from other ways of knowing, such as history, art, philosophy, and religion. Scientists attempt to explain natural phenomena, and are not involved in questions that cannot be answered by science, such as whether God exists. Third, science address questions about the natural and material world. It does not seek to answer questions outside the natural world. Those questions are important, but cannot be answered by science. Third, scientific knowledge assumes an order and consistency in natural systems. By assuming this order we can search for patterns in data and empirical evidence, and then make predictions and form generalizations to explain the natural world. And fourth, science is a human endeavor, meaning data are subject to human interpretation and creativity, as well as being theory-laden and subjective, and socially and culturally embedded.

NOS and Scientific Inquiry—Influence of Research

There has been ample research on student and teacher understanding of NOS as well as scientific inquiry over the past six decades. While it is clear that student and teacher conceptions can improve, generally the same misunderstandings are held by students and teachers now as they were decades ago (Lederman, 2007). Unfortunately, these misconceptions about NOS and scientific inquiry clearly mean that little progress has been made in helping students and teachers attain scientific literacy. It is clear from empirical research that student and teachers' learning about NOS and scientific literacy is most effective through explicit reflective instruction (Lederman & Lederman, 2014). Explicit reflective instruction requires teachers to facilitate discussion and reflection about the very nature of science itself as investigations are taking place, or as they are debriefed after being concluded. Therefore the students will be explicitly reflecting on ideas about NOS as part of their science instruction.

However, this explicit reflective instruction rarely takes place. Unfortunately, despite the empirical research, there is little change to curricula, or classroom practice. The act of embedding NOS explicitly takes tremendous effort in adapting lessons and ensuring it is completed (Akerson, Pongsanon, Nargund, & Weiland, 2014). It is not typically included in curricula, and therefore even teachers who want to include it need to spend much time in adapting lessons. This lack of emphasis on NOS in the curricula has influenced the amount of NOS instruction that takes place in a science classroom—it is still very little, unless a teacher is very committed to such instruction.

Now, not only are K-12 teachers to teach about science, including NOS, but they also need to include connections to technology, engineering and mathematics—STEM. And maybe art too, if they are teaching "STEAM." Or if you are at Indiana University and have no engineering department, "Informatics" instead of engineering, and you are "STIM." However, with teachers still struggling to not only teach about NOS, despite the years of empirical research supporting teaching methodology for effective NOS instruction, it definitely means our job in teacher preparation will entail even more, to prepare teachers for what they need to do. If they need to conceptualize the Nature of Science as a way of knowing, certainly they should be able to conceptualize other ways of knowing that are part of STEM—in essence, what is the nature of the "TEM?"

Defining the Nature of the "TEM"

As a science educator, but also a part of current society, I sought to locate statements on the nature of technology, the nature of engineering, and the nature of mathematics. I did what anyone would do—a Google search. In this way, I was able to find what anyone would commonly find when doing such a search. I conducted this search for definitions of the Nature of Technology, Nature of Engineering, and Nature of Mathematics. These definitions will be reported in the sections below.

Nature of Technology

When searching for information regarding Nature of Technology, I was able to locate an entire book (Arthur, 2011) that described "The Nature of Technology: What it is and How it Evolves." In essence, the Nature of technology involves three definitions. First, technologies are combinations of elements that exist. Second, the elements that comprise technology are technologies themselves. Finally, all technologies use phenomena to some purpose. Therefore, technology is purposeful. In addition to these three definitions of technology, Arthur adds three meanings of technology to the nature of technology—or the characteristics of technology. First, there exists individual technologies, or "a means to fulfill a human purpose." Technology, again, is purposeful, and the purposes are to solve issues or problems of a human nature. The second includes the bodies of technologies, such as semi-conductors, or robotics, or "an assemblage of practices and components." This portion of the definition to me is similar to the content part of science—the "stuff" of technology. The third meaning of technology is its largest sense, "The entire collection of devices and engineering practices available to a culture, and is dependent on scientific knowledge." This portion of the definition, as I read it, comprises the content, products, and practices of engineering, more of the "nature" of technology.

Nature of Engineering

A search for a definition of the Nature of Engineering enabled me to locate the National Academy of Engineering's president Wulf's definition from 1997. They state simply that, "Engineers apply their knowledge in science and mathematics to design and create things, develop existing technology, and invent new methods and processes." Their definition is very brief and there did not seem to be an updated definition, at least not one that turned up easily in the search. Regarding the definition, it is apparent that engineers base their designs, in part, on their scientific knowledge, and use that to develop new ideas, processes, and technologies. Note that there is no description of the "engineering design process" that is part of many K-12 STEM curricula.

Nature of Mathematics

Like the search for the definition of the Nature of Engineering, my search for the definition of the Nature of Mathematics similarly turned up an older document—this time a full book chapter within the *Handbook of Research on Mathematics,* by Dossey (1986). A search for a more current version was not readily found, so I used this chapter. From this chapter I gleaned that mathematical objects are invented or created by humans. These creations are not arbitrary, but arise from activity with already existing mathematical objects, and from the needs of science and daily life. Once these mathematical objects are created they have properties that are well-determined with we may have great difficulty in discovering, but which are possessed independently of our knowledge of them. To me, this means that mathematics is also a problem-solving entity that is also connected to science, as its creation arises as a result of the needs of science. Once it exists and is created by humans, it has characteristics that then remain, independent of human knowledge about them.

Back to STEM

If we are going to teach STEM as a discipline itself, do we need to prepare teachers to understand the nature of each of these disciplines that comprise STEM, as well as the connections among them? It seems that teachers would need to know the natures of the disciplines they are to teach. But if we haven't been successful in the past in helping teachers better conceptualize nature of science, as well as teach it, how can we help them better conceptualize all four disciplines, plus the connections among them, and then teach these ideas to students? A search for a definition for the nature of STEM yielded no results. Does this mean that we need to define what is exactly the nature of STEM? Would that be the way to go, to have only one term about which to conceptualize its nature?

And what about scientific literacy? Do we now focus on STEM literacy instead? But if we cannot agree on a definition of scientific literacy can we agree on a definition of STEM literacy? Bybee (2013) offers the following suggested definition of STEM literacy:

> (1) Knowledge, attitudes, and skills to identify questions and problems in life situations, to explain the nature and designed world, and to draw evidence-based conclusions about STEM related issues.
>
> (2) Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design.
>
> (3) Awareness of how STEM disciplines shape our material, intellectual, and cultural environments
>
> (4) Willingness to engage in STEM issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen.

It would seem evident that to demonstrate STEM literacy, as defined above, individuals would need to conceptualize the nature of the disciplines that comprise STEM, as well as the kinds of knowledge generated in each discipline, along with the connections among them. Not an easy feat to conceptualize these, or to teach these ideas. How then, do we get to STEM literacy? If we look back at the definitions of the "TEM" in STEM, we can see that Nature of Technology—is dependent on *scientific* knowledge, Nature of Engineering—Engineers apply their knowledge in *science*, and Nature of Mathematics, mathematical artifacts are created not arbitrarily but arise from activity with already existing objects, and from the needs of *science*. All the other disciplines in STEM connect somehow to science. It seems the “S” in STEM is important.

This insight into science being a very important component of STEM raises the question how can technology, engineering, and mathematics progress without an understanding of science and its nature? Science is a part of each discipline’s nature. It would be difficult for these disciplines to make progress without understanding the nature of scientific knowledge. Therefore it is not only important for NOS to be understood by those studying science, but also those studying STEM disciplines.

Therefore, I raise a call for renewed emphasis on research on NOS in science as well as STEM. How can accurate conceptions of NOS influence conceptions of STEM? What does an accurate conception of NOS mean for those who operate in the STEM field, or for those required to teach STEM K-12?

We need a definition of STEM that we can agree upon, as well as a definition of the nature of STEM. How do we know when we are “doing STEM?” Many projects claim to be STEM projects or programs, but what are the natures of those projects—are there some essential components that are necessary to be included in order to be labeled “STEM?” Or to be labeled “good STEM?”

Are there different kinds, or levels of “STEM?” What does it mean to be STEM? And yes, the S in STEM really is that important—we need to know NOS as part of scientific literacy, but also as part of STEM literacy. There is no STEM without the S.

CONCLUSION

Let us all work hard with our research toward resolving these issues about defining STEM and its nature. And not only just conduct the research, but also make impact on classroom practice. The research on teaching NOS effectively is clear, yet still little change has been seen in classroom practice. Making an impact on classroom practice is easier said than done, as past research on teaching NOS has shown. Hopefully working together to define these ideas we can make better, and quicker, impact, helping improve scientific and STEM literacy.

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What is Technology (T) and What does it Hold for STEM Education? Definitions, Issues, and Tools

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The Conception of Technology

Scholars and politicians in the field of education acknowledge the potential and promise of technology for learning and teaching. It has recently become the most important and urgent agenda in most of the countries' educational policies and curriculum developments. In fact, it is often considered as a quick solution to our educational challenges. We, as educators, are clear that technology opens new horizons for students, teachers and educational settings. Nevertheless, decades of research and personal experiences have shown that technology integration into schools is a complex and multi–dimensional process. Effective and successful technology use in the educational settings requires us to know and work on several factors and make them to be consonant with each other. The first perhaps the most important one is to have a comprehensive conception of technology because it directly contributes to the development of teachers' belief systems. While some factors have been disappearing with the increased access to technology and improved teachers' relevant competencies, teachers' beliefs persist to be a key factor as they are robust and resistance to change (Ertmer, 2005).

Unless we have a clear understanding of what technology actually means, we will most probably miss the point of pedagogical value and transformative role of technology in education and thus fail to achieve a true and beneficial integration. The result would likely be a technically–oriented and superficial implementation and ultimately an unprofitable investment. Being an overly optimistic or pessimistic about technology will also lead to the adoption of it either as a magic wand to fix educational problems or a threat to disrupt educational activities. A recent study in Turkey shows that pre–service teachers have a restricted conception of technology mostly focusing on artifacts and technical characteristics, and calls for a teacher education culture and curriculum that emphasize a broader and balanced view of technology (Koc, 2013). It is well–known that teachers' pre–existing beliefs and views act as a filter for the acceptance of new knowledge and tools and significantly shape their usage in general teaching practices (Pajares, 1992; Richardson, 1996).

This is also true for teachers' specific technology integration practices (Ertmer & Ottenbreit–Leftwich, 2010). Therefore, providing teachers with a well–rounded conceptual base about the nature of technology is a first vital step because it influences how they adopt and apply technology in their pedagogical acts (Koc, 2013).

The word of "technology" is known to be derived from Greek words "techne" referring to manufacturing (e.g., techniques of tablets, 3D printers) and the arts (e.g., techniques of teaching, drawing) and "logic/logos" meaning word, thought, speech or principle. From this linguistic aspect, technology is defined as an endeavor or study on making a craft or mastery of an art. This is why it is prevalently known as the application of scientific knowledge and skills to our practical problems. It is not a distinct discipline itself but rather a practice of any discipline like constructive technology, educational technology, medical technology, and so on. This definition obviously involves both a tool/end and its process of production and consumption. However, our everyday understanding of technology is often bound to its instrumentalist perspectives. When talking about the use of technology in education, we usually refer to only technological tools and its features (e.g., tablets, robots, interactive boards). As we explain in the following sections, such a conception represents a restricted view of technology and its implementation. Strict subscription to this school of thought can hinder to think about and plan technology integration in detail and hence may lead to be unsuccessful or ineffective in this affair.

A closer look from the philosophical perspective reveals diverse approaches to understanding the meaning of technology and its consequences on human life. In his book, Critical Theory of Technology, Feenberg (1991) distinguishes various theories in terms of their prepositions about the nature of technology on two continuums. One indicates the extent of autonomy; technology is either autonomous or human–controllable. The other illustrates the degree of value–ladenness; technology is either neutral or value–laden. Based on the intersection of these continuums, he identifies four main types of theories of technology: instrumental, deterministic, substantive, and critical view.

The "instrumentalist perspective", often optimistic about technology, view technology as morally neutral and human–controllable. Technology is usually identified as anything mechanical or electrical tool that can be used for achieving a pre–determined end, either bad or good, and can be humanly controlled. According to Feenberg (1991), it is subservient to values established socio–cultural and political spheres. While technical aspects including appearance, utility, popularity, and aesthetic features are usually highlighted, factors such as the historical context and social shaping of a technology, human experiences and activities surrounding the technology are not considered. As we mentioned earlier, it is the most widely accepted view of technology not only in education sector but also in all other areas of the society. Technology is viewed as a rational and universally applicable entity so it is free of cultural, political, and ideological values. Due to this decontextualization, technology is expected to function in the same way and serve the same purposes anywhere it is used regardless of where it is originally produced. Moreover, technology itself and its consequences on human lives or society in general are considered to be independent of each other. Individuals are responsible for proper or improper usage of the technology, not the technology itself. The neutrality assumption has been criticized due to its ignorance of possible political, social, and human influences on the process of technology development and implementation. For example, Pacey (1992) gives an example of snowmobile use in Canada and North America. He points out that snowmobile is always regarded as the same machine whether it is used for earning a basic living, recreation, or environmentally destructive sport. He further argues that when a technology fails or has unintended or negative results, according to the instrumentalist view, the technology itself should not be blamed but rather "its misuse by politicians, the military, big business and other" is the causal factor (p. 2).

"Technological determinism" is another prevailing way of thinking about technology and its function in the society. It argues for a one–directional relationship between technology and society in which the former develops apart from the latter and autonomously causes social change and directly impacts people (MacKenzie, 1998). It is very popular and highly adopted among the politicians and development institutions. They usually advocate technology as the cause of success or failure (e.g., learning problems, low achievement, and high efficiency). According to Feenberg (1991), technological determinism is based on the following two arguments:

1. The pattern of technical progress is fixed, moving along one and the same track in all societies. Although political, cultural, and other factors may influence the pace of change, they cannot alter the general line of development, which reflects the autonomous logic of discovery.
2. Social organization must adapt to technical progress at each stage of development according to the "imperative" of technology. This adaptation executes an underlying technical necessity (pp. 122–123).

Technology impacts everyone's life because more aspects of life in technological/networked society are becoming mediated by the use of digital technologies. According to the technological determinist position, people generally do not have any influence over the direction of technological evolution and thus technology is an autonomous and revolutionary force characterized by two oppositional perspectives: utopian or dystopian. The utopian position constructs technology as a positive and uplifting force that addresses and ultimately eradicates much of human misery while increasing opportunities for social progress. It is the common sense perspective and is associated with an enlightenment scientific–based social narrative of progress. This perspective, for instance, suggests that information and communication technologies liberate societies through facilitating an increase in social and economic capital and democratic participation (Katz & Rice, 2002). A dystopian perspective, on the contrary, believes that technology is an inherently dehumanizing force that will lead to social and physical destruction of society. For example, Postman (1992) and Slouka (1995) argue that the main problem of technology is its increasing isolation of people within virtualized simulations of reality that cuts them off from the real natural world. Based on the notion of social constructivism, some scholars propose “social construction of technology approach” to dispute technological determinism (MacKenzie & Wajcman, 1999). The relationship between technology and society is claimed as the opposite of what is claimed in technological determinism: the latter shapes the development of the former. The proponents of this approach assert that technology is not immutable but is a dependent variable characterized by human engineers, market forces, consumer needs and demands, and all other social factors.

Unlike the instrumental approach, the “substantive theory of technology” treats technology not a neutral tool, but rather embedded with values and ideologies in order to “constitute a new type of cultural system that restructures the entire social world as an object of control” (Feenberg, 1991, p. 7). It also holds that technology is autonomous and “tends to function independently of the system it serves…in the manner of a robot that no longer obeys its master” (Postman, 1992, p. 142). From this point of view, it resembles the theory of technological determinism. The substantive theory asserts an underlying essence or autonomous force to technology that overrides all traditional and competing values. Social changes are believed to be influenced if not determined by technological innovations since technology is fundamentally defined more than a machine and can very well embody or constitute social and cultural dimensions that may involve profound alterations for societies. Therefore, technical progress can overcome human willpower and have a substantive impact on individual ad community which, according to Ellul (1990), can be in three kinds: the desired, the foreseen, and the unforeseen.

The substantive view is best known through the work of Ellul and Heidegger. Ellul’s (1964) book, *The Technological Society*, describes the gradual process by which technology is subverting and absorbing the traditional values of human society. Ellul specifically defines technology as “la technique” which he defines as “the totality of methods rationally arrived at and having absolute efficiency (for a given stage of development) in every field of human activity” (1964, p. xxv). He argues that the technical erodes the bonds of traditional social groups, communities, and human relationships without building new social structures in their place. Technique itself becomes the central focus of society as the human being is progressively transformed into the object of technique (Ellul, 1964). Heidegger (1977) approaches the essence of technology from an ontological perspective and associates it with his concept of "Dasein", the essence of "Being". For Heidegger, the essence of technology relates to how technology as a phenomenon is "coming to presence" or evolving via human actions. He introduces the concept of "enframing" as the essence of technology, which is a way of understanding being, or as he phrases, a way of revealing. He argues that "techne" is a kind of knowing and its essence lies not in manufacturing goods or using tools, but in revealing. The danger of technology, for Heidegger, is that the machines begin to alter human existence and shape human destiny, and therefore, prevent individuals from understanding their own being and natural objective identity. Complementing this notion, Feenberg (1991) claims:

> The issue is not that machines have "taken over", but that in choosing to use them we make many unwitting cultural choices. Technology is not simply a means but has become an environment and a way of life: this is its "substantive" impact. (p. 8)

Criticizing and synthesizing instrumental and substantive views of technology, Feenberg (1991) proposes a "critical view of technology", a dialectical approach, in order to reveal the complex relationships between modern society and technology. He (1991) rejects the "autonomous" premise of substantive argument and the "neutrality" notion of instrumental view. However, he adopts the value–ladenness premise of the former and reflects the latter's argument that technology is under human control. According to Feenberg (1991), critical theory uncovers the values and assumptions influencing the design and construction of a technological tool. Being a valuable alternative discourse, it challenges the idea of being trapped into the dilemma of either accepting whatever technology is available or assuming a useless anti–technological position. The critical perspective considers a given technology in terms of not only its design phase but also its diffusion and use contexts. Thus, technology and society are seen to be dialectically intertwined.

Having been influenced by the work of Marx and Marcuse, Feenberg (1991) refers to the concept of "technological ambivalence" by examining Marx's three critiques of technology to uncover the connection between capitalism and technology: (a) "product critique" which focuses on the purposes for which technology is designed, (b) "process critique" regarding how technology is employed to accomplish those purposes, and (c) "design critique" related to the ways in which technical principles are applied in the design of technology (pp. 31–32).

According to his critical analysis:

> Technology is not a thing in the ordinary sense of the term, but an "ambivalent" process of development suspended between different possibilities. This "ambivalence" of technology is distinguished from neutrality by the role it attributes to social values in the design, and not merely the use, of technical systems. On this view, technology is not a destiny but a scene of struggle. (p. 14)

The term "technological ambivalence" emphasizes the various kinds of possibilities and choices available to society regarding technology adoption. Moreover, the decision process which reviews these potentialities is social, not technological, and involves complex social, cultural and hegemonic power relations. Feenberg, referring to work of Marcuse and Foucault, proposes that such decisions are mediated by a "technical code" that represents certain values and interests of the dominant social groups, and that ideas at the design phase of technology reflect "capitalist rationalization" of the modern society. For this reason, "technology is a dependent variable in the social system, shaped to a purpose by the dominant class, and subject to reshaping new purposes under a new hegemony" (p. 35). Different values and choices of designing certain technologies may frame different possible ways of life. This can be achieved, in Feenberg's sense, through democratic means including greater participation in the design and development of technology.

Our intention for reviewing these views is to illustrate that there is not a unique philosophy of technology and its implications for a society. Besides, technology itself is constantly changing and developing from day to day. Therefore, understanding technology and its consequences on a society requires the engagement of various theories and practices in other disciplines as well. The aforementioned views suggest that the relationship of technology with any social institutions remains complicated. This also applies to education. They indicate how technology integration into education is a complex and uneasy issue from not only practical but also philosophical aspects. Each theory has both strengths and weaknesses. Educators need to know all philosophical approaches to technology and its implications for education so that they can develop a broader and balanced personal standpoint of technology integration. Combination of diverse perspectives might also contribute to the development of analytical frameworks for determining and implementing optimal educational policies.

The Role of Technology in STEM Education

From the above review of various thoughts of technology, we now realize that the term "technology" should refer to not only technical tools but also human activities including multifaceted organizations and value systems. This realization involves more comprehensive and precise conception of technology. To make such a general and systematic meaning of technology, Pacey (1992) proposes the concept of "technology–practice", which is "the application of scientific and other knowledge to practical tasks by ordered systems that involve people and organizations, living things and machines" (p. 6). He categorize technology–practice into three general aspects: (a) organizational aspect that consists of activities of the designers, engineers, factories, users, and consumers, (b) technical aspect that refers to machines, techniques as well as the knowledge and skills to operate them, and (c) cultural aspect that means values, ethical codes, awareness, and creative activity, which influence the designers and inventors of technology. He considers the "technical aspect" as a restricted meaning of technology, and defines the general meaning by including all three aspects together which constitutes the concept of technology–practice. We believe that Pacey's (1992) conceptualization is very appropriate to explain technology integration in educational settings. When we talk about the use of technology in teaching or learning, which is a special case of technology–practice, we need to consider all technical, organizational and cultural aspects.

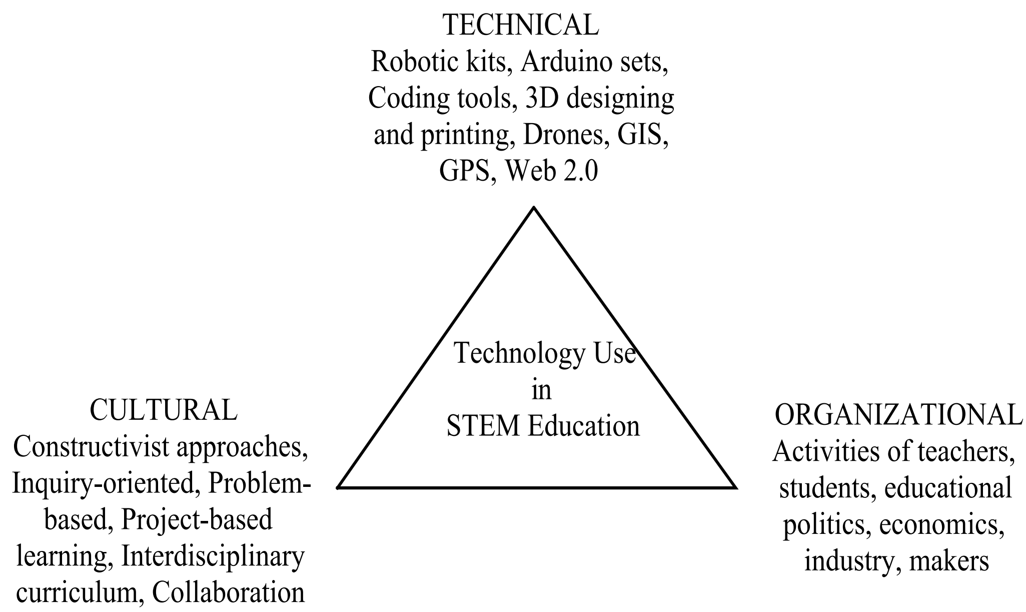

Figure 1. A Framework for Technology Use in STEM Education

Using Pacey's (1992) general conceptualization of technology–practice as a theoretical base, we propose a three–legged framework for technology use in STEM education (Figure 1). Our framework highlights that effective technology integration to support STEM attitudes, knowledge and skills requires the consideration and coordination of technical, cultural and organizational factors. As suggested by the aforementioned philosophical perspectives of technology, it considers not only technological devices but also relevant human activities surrounding them and the values influencing their production and consumption. Hence, it acknowledges technology use in STEM education as not value–free and neutral.

All three factors need to work together to comprise technology implementation into STEM approach. Just like a tripod lost the stability when any of its legs is broken down, technology integration may also fail when any of these is neglected or has some deficiencies or impairments.

The first aspect "technical context" refers to hardware and software tools that support the development and implementation of STEM–based learning activities. Examples of currently available ones include but not limited to robotic kits, arduino sets, coding programs, 3D printers, cloud computing, geographic information systems (GIS), global positioning systems (GPS), Web 2.0 tools. In the proceeding section of this chapter, we introduce some of these tools in detail and discuss their educational potentials. Technological tools to be used for STEM activities are expected to include manipulative options through which students can design, develop and program interactive artifacts (Ortiz, Bos, & Smith, 2015). In this way, they are able to observe the consequences of the changes they make on some factors on the status of others (e.g., casual relationships between independent and dependent variables). Such tools also promote computational thinking, systematic reasoning, creativity and problem–solving, which are among the skills that we must teach our children in the 21st century. One another benefits of these technologies is to engage students in hands–on experimentation through which they can collect and analyze contextual data and translate abstract mathematics and science concepts into concrete real–world applications (Nugent, Barker, Grandgenett & Adamchuk, 2010).

Schools needs to plan a special budget for integrating STEM learning activities as accessing related technologies is relatively expensive. This may not be easily achieved by those public schools especially in the developing countries where such tools are usually imported. Technical infrastructure is an essential determinant of technology use in STEM education. Istanbul Aydın University organized the First STEM Education Workshop in 2015 in order to identify deficiencies and gaps in the Turkish K–12 and higher educational system germane to STEM and then suggest curricular and practical solutions to overcome these shortcomings. This was a comprehensive assessment of STEM implementation in Turkey with the participation of academicians, experts, administrators and teachers. The workshop report concluded that the most crucial shortcomings were related to such issues as interdisciplinary cooperation, teacher competency, technical infrastructure, student guidance, measurement and evaluation, curriculum integration and STEM courses (Akgündüz, Ertepınar, Ger, Sayı & Türk, 2015). Technical infrastructure here involves labs, ateliers and related technological equipments. It is the core element and thus any problem in its presence and function is automatically reflected in other issues, especially STEM practices in the schools.

It is again important to acknowledge that, as our framework emphasizes, equipping schools with STEM–related technical tools is necessary but it alone is not adequate to ensure successful implementation. Organizational and cultural contexts should be considered as well. Unfortunately, technical aspects usually come to the forefront while others are less considered, if not completely ignored, in the process of technology integration. This gives the impression that capitalistic, populist and instrumentalist thoughts and movements seem to be more dominant than social, humanistic and pedagogical ones. Çepni (2017) argues that the presentation and perception of advertising and marketing readily–prepared/assembled tools (e.g., robotics, electronic circuits, coding) that are not associated with math and science learning objectives is one of the biggest mistake in STEM adoption in Turkey. He warns that such an approach may lead to the inflation of performing activities opposite to STEM philosophy (i.e., consumption–oriented rather than production–oriented) and eventually emergence of a STEM–tools garbage. Therefore, technical context need to be grounded on a well–established philosophical and scientific base.

The second aspect "cultural context" involves educational philosophies, policies, theoretical beliefs and values related to teaching and learning, and curriculum objectives. Such issues have direct influence on the determination of the role of technology in the schools. Technology integration has been defined by the activities and indicators of how teachers and students use technology. Prior studies reveal that in many cases, it has meant different things to different people, and the term appears to have evolved over the years. Therefore, how technology should be utilized in the schools has been an ongoing discussion among the educators. Generally speaking, three conditions stand out when thinking about the possible ways of using it for educational purposes: learning about technology, learning from technology, and learning with technology.

Learning about technology represents the awareness and literacy of technological tools. In this way of using technology, the aim of education is often the technology itself and to teach student how to operate it. This is usually observed when a specific technology is first introduced and diffused to a society and thus can be described as the beginning stage of technology integration. Learning from technology represents behaviorist perspectives for learning. Technology is usually programmed either to deliver education content or to offer drill–and–practice activities. The interaction between technology and a learner is one–directional from technology to the learner. It can be described as the intermediate stage of technology integration. Finally, learning with technology represents constructivist approaches to learning in which learners are decision makers and active participants of knowledge construction with the help of technological tools to support learning goals. It can be identified as the advanced stage of technology instruction. A critical review of literature on effective technology integration reveals that learning from technology is not the most effective way to improve learning in spite of helping learners to gain lower level sub–skills easily and perform them automatically whereas learning with technology is well–suited for meaningful learning by encouraging learners to actively process and organize information (Koc, 2005).

STEM education is mainly based on the constructivist epistemology because it advocates critical thinking, creativity, problem–solving, designing and productivity, entrepreneurship, authentic learning experiences and performance–based assessments (Çepni, 2017), which all are also premises of constructivist learning. Constructivists believe that humans have the ability to construct knowledge through an active process of discovery and problem solving. They regard technology as assistant for knowledge construction. In constructivist use of technology, fundamental tasks of learning such as planning, decision–making, and self–regulation are the responsibility of the learner, not the technology. Technical tools which support constructivist learning are often defined as cognitive tools, whose core attribute is not in the information that they carry, but the forms of learner activity and engagement that they support and encourage. In a similar vein, Jonassen (2000) developed the ideas of "mindtools": computer based tools that have been "adapted or developed to function as intellectual partners with the learner in order to engage and facilitate critical thinking and higher–order learning" (p. 11). According to him, the role of a mindtool is to extend the learner's cognitive functioning during the learning process, and to engage the learner in operations while constructing knowledge that they would not have been able to accomplish otherwise. "Mindtools enable learners to become critical thinkers. When using cognitive tools, learners engage in knowledge construction rather than knowledge reproduction" (p. 18). Therefore, it is reasonable to say that those technologies with cognitive tool characteristics are highly suitable for STEM education. Technology can be very functional to support meaningful learning when it is used to engage students in active, constructivist, intentional, authentic and cooperative learning (Jonassen, Peck & Wilson, 1999). Such engagements are also sought in STEM approach to prepare students as productive workers of future workplace. In fact, some constructivist strategies approaches including inquiry–oriented, problem–based, and project–based learning have been applied to improve STEM education (Kim et al., 2017).

The third aspect "organizational context" refers to appreciation of technology as human activity and part of life. It represents many facets of educational administration, policy makers, academics, teachers, students, and related professional organizations. It makes explicit the role of such actors in technology integration. Any attempts for STEM–related technology practices in the schools should be primarily driven by educational stakeholders and organizations, not the external political and economic environments and imperatives, as we frequently encounter. Çepni (2017) indicates how STEM is increasingly represented in exhibitions, fairs, clubs rather than educational institutions and their programs as one of the mistakes being made in STEM practices in Turkey. Teachers ought to embrace STEM and diffuse its innovations within their educational environments. Moreover, the success of technology integration depends on its actors' adaptation to technical and pedagogical changes. Teachers are the key role for making any changes in education. As Hargreaves (1994) points out, "the involvement of teachers in educational change is vital to its success, especially if the change is complex and is to affect many settings over long periods of time" (p. 11). The organizational context emphasizes an alignment and compatibility between the design and development of STEM technologies and the implementation of them in the schools. Educators should take active role in both phases to prevent from the potentials gaps and mismatches.

Effective teacher preparation is the most crucial enabler for using STEM technologies. Teachers should be taught about how to operate related devices and implement them as learning and teaching tools as well as given the best examples of technology use accordant with STEM concepts and principles. This is required for not only computer teachers but also all branch teachers because STEM emphasizes an interdisciplinary approach. However, we observe that pre–service teacher education programs in Turkey do not have adequate technology courses. Just like a number of pedagogical formation courses to gain general competencies of teaching profession, there should also be technological formation courses to gain STEM–related technological knowledge and skill sets. Professional development activities (e.g., in–service training programs, congress/symposiums, publications) and incentives can also be offered to school communities in order to be adapted to STEM technology implementations and related new roles.

Current Technological Tools for STEM Education

STEM in education plays a critical role in preparing students for careers as adults. Nearly 80% of future careers will require some STEM skills. Therefore, a stimulating STEM education is essential for developing the basic analytical, problem–solving and critical thinking skills central to academic achievement and workforce readiness in the 21st century (Moeller, 2012). Technology in STEM subjects refers to tools that make abstract ideas more concrete and accessible through experiential learning and provide dynamic representations of STEM systems to enhance student learning of complex concepts. As psychologists and philosophers have long argued (Clark & Chalmers, 1998) that technology in STEM education has the potential to promote sensory motor experiences which has a vital role on cognitive development. These technological tools provide opportunities for learners to explore and examine abstract concepts in concrete ways. Technological tools both digital and hardware may provide concrete, hands on, graphical symbolic experiences in STEM teaching and learning environments. They make students accessible to design, explore and test the knowledge they acquired at varying levels. A wide range of digital technologies may provide opportunities for students to develop a formal model of a real world situation to carry out safe and efficient simulated virtual experiments in both formal and informal learning environments and to realize their project ideas in project based learning conditions.

Technology offers many opportunities, as a contributory subject, for the teaching of STEM content through enabling tools and practical application of skills (Sidawi, 2009). It plays a vital role in instruction as well as STEM teaching and learning but it requires careful integration. Even the latest state of art technological tool may not replace human social interaction or good teaching. Therefore, students may need scaffolding, guidance and caring during the learning process. For a successful STEM education, we need to use the technology to solve complex problems that work across the disciplines. To achieve this goal, we, as educators, need to blend technology in methods that help to scaffold and develop independent learning in our students (Davies et al., 2013). According to Pasnik and Hupert (2016) technology STEM learning and teaching can be enhanced if technology is used to provide models, promote social interactions, collaborations and opportunities to develop science skills, practices. As we argued earlier, technology use in STEM should focus on learning with technology rather than learning from technology. The following are a short introduction of the most popular STEM technology tools, hardware and software that teacher can facilitate in their STEM teaching both in formal and informal learning environments.

3D Printing

Three dimensional (3D) printing, also known as "additive manufacturing" or "rapid prototyping", is a manufacturing process that builds layers to create a 3D solid object from a digital model created with computer–aided design (CAD). Objects are constructed based on their digital graphical model using a layering process and printed using various materials such as: rubber, metal, plastics, and even sugar or hot cacao powder (Figure 2). It is a rapid prototyping technology that has gained increasing recognition in many different fields. 3D printing technologies for creating tactile experiences offer revolutionary ways of conveying spatial information and multimodal learning. They offer economical alternative to creating 3D models that increases opportunities for customization and experimentation in educational and medical implications. 3D printed models can offer innovative ways of understanding spatial concepts for objects that would otherwise be too large, small, valuable, or dangerous to hand to a student in teaching and learning process.

3D printers are gaining popularity internationally across STEM education. In order to prepare today's students to take on STEM jobs in their futures, they need to experience STEM subjects in an engaging, exciting, and hands–on way. 3D printing as a multisensory experience is a great way to make this possible. Therefore, 3D printing technology is critical to raise students up for a competitive world particularly in STEM contexts (Easley, Buehler, Salib & Hurst, 2017). It has a radically transformative effect and can support vital skills development in many subject domains. It has implications most obviously for creative thinking and design. Therefore, there is a considerable potential of 3D printers. For instance, it enables links to be made between mathematics, design and physics. Furthermore, in science education, 3D printers can be utilized to present atomic structure in Grade 10 Chemistry classes, with a positive correlation found between its integration into instruction and learning (Chery, Mburu, Ward & Fontecchio, 2015). Additionally, 3D printers can be utilized in a context to discuss the properties of plastics, to build models for teaching science such as molecules, eye–balls, cells and sine waves, and to build components for working equipment such as rockets in integrating science teaching into STEM. In Mathematics, for instance, 3D printer can be utilized to demonstrate a 3D graph for various algebraic equations as well as producing examples of regular shapes.

3D printing technology is proving to be one of the most adaptable and innovative technologies of the 21st century, with diverse applications spanning medicine, engineering, art, design and even the domestic realm. Therefore, they offer an opportunity for schools to explore innovative ways of teaching STEM subjects, stimulating students' interest and enriching the curriculum. This evolving technology is also being used in the education sector, transforming the STEM curriculum and creating powerful learning tools. 3D printing experiences enrich the learning environment providing students with hands–on experiences using an actual manufacturing tool and generate numerous creative and useful products.

Utilizing 3D printers requires hands–on skills technique and being able to follow step–by–step instructions which are relevant to STEM related career. Even though the use of 3D printing technologies is relatively new in educational settings, the disciplines of architecture and engineering were early adopters of additive manufacturing technologies (Celani, 2012). Students in engineering, especially mechatronics, mechanical engineering and also architecture are expected to master CAD programs. Therefore utilizing 3D printers in STEM education is crucial to prepare them to the future STEM careers. 3D printer can be utilized in two ways in STEM education. First, STEM learners can use 3D printers for the process of making the 3D print file and print the tactile object using a 3D printer as a design and production phase. The second, using 3D printers as a way to experience a tactile object that would not be possible without touching or handling the 3D print itself (Kolitsky, 2014). 3D printers can be used to create 3D replication of famous artists' art works in order to examine them by touching which would not be possible in real world. 3D printing can also enable students who are blind to experience visual art.

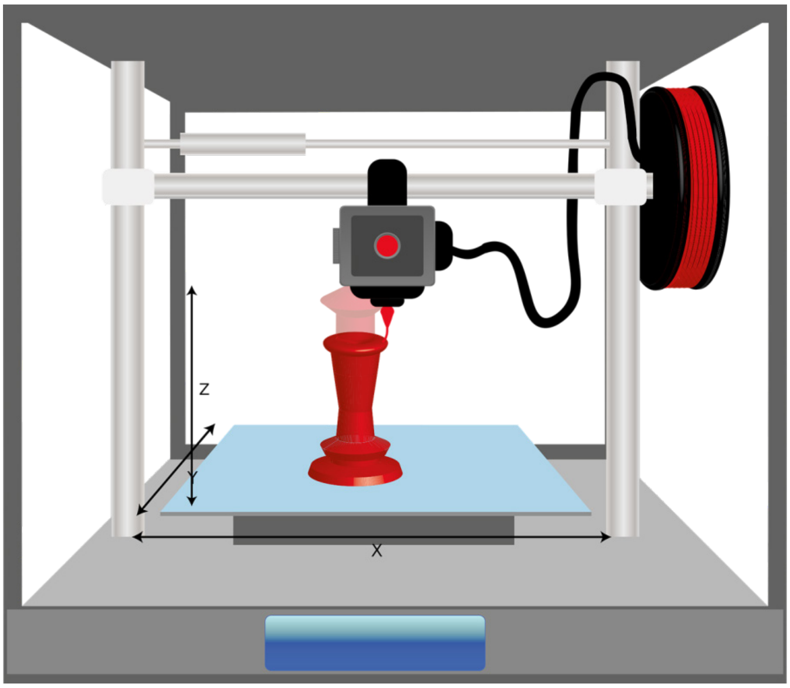

Figure 2. Graphical Representation of 3D Printing

In order to integrate 3D printing and design into STEM classroom, teachers and students need to utilize 3D design software to modify and create parts. CAD and computer–aided manufacture (CAM) contributes to developing students' practical skills to "achieve a professional quality" (Ofsted, 2011 as cited in Jones, Tyrer & Zanker, 2013). The most common 3D design and CAD programs that work well for teachers are SketchUp and ThinkerCAD. Other programs such as Solidworks and Autodesk 360 can be too complex to start with for beginners.

SketchUp

SketchUp is a design program that was supported by Google. It is a very crisp program that clearly shows how objects are forming. In other words, it shades the sides so that students easily know which side of a cube is the top.

It has reference features in the viewport so that students can easy know which direction is up or right or left regardless of what angle they are looking at an object from. SketchUp uses the same methodologies as more advanced design programs to create shapes. They have you draw a sketch on a 2D plane and then that sketch can be "extruded" to create a 3D shape.

The disadvantage of SketchUp is that it is not very 3D printer friendly. The Beta Cloud version does not generate .STL or .OBJ files which are necessary to 3D print an object.

The desktop version of the software can export those files, but it is not as simple as other programs. Overall, SketchUp is a good program for introducing CAD in general to beginners.

ThinkerCAD

ThinkerCAD is a program created by Autodesk. It allows beginners to drag and drop basic shapes into a workspace and then reshape them. Student may place a cube into the workspace and then grab the edges and corners to turn it into a board or some other rectangular prisms. When it comes time to create a file for 3D printing, TinkerCAD allows saving and exporting in 3D printing formats (.stl, .obj.). It is entirely cloud–based, so schools that have moved away from desktop labs can use it easily. The downside of TinkerCAD is that it is highly dependent on dimensioning. However, overall it is an excellent program to start students out with.

Robotic in STEM

Robotics in K–12 STEM education is a growing field and getting popular at all levels each year. Studies show that robotics can be utilized in STEM education for a variety of purposes such as motivating students to seek STEM careers (Ruiz–del–Solar & Aviles, 2004), improving critical thinking and problem solving skills (Eguchi, 2014; Ricca, Lulis & Bade, 2006), enhancing students' ability to solve logical and mathematical problems (Lindh & Holgersson, 2007) and encouraging collaboration and team work (Eguchi, 2016; Weinberg, White, Karacal, Engel & Hu, 2005).

The notion of using robotics in education goes back to earlier research on Seymour Papert's LOGO programming work in the 1970s. He created LEGO programming language that children can program computer and robots to gain sense of control over technology. Papert believes that students learn better when they are experiencing and discovering things by themselves (Papert, 1980). According to Slangen, Keulen and Gravemeijer (2011), robots can be utilized to do math and science rather than study them by contextual learning with the premise that an engaged student learns better. With the help of STEM educational robots students can take the knowledge from math and physics and apply them to real world situations. For instance, in order to assign a task to a robot, students needs to apply their coding, math and physics knowledge in to practice (Eguchi, 2014).

There is an increasing reliance and dependence on technology and computer programming in today's society. Educational STEM robots can bridge this gap by bringing basic programming languages allowing students not only have fun but also learn coding to prepare themselves in the future competitive market. STEM robot kits allow students to learn concepts through trial and error, application, and hands–on experiences, ensuring that they understand what they are dealing with. Many educational robotic kits are used in all educational levels such as Lego Mindstorms and mBot.

mBot

mBot is an entrance level educational robot, suitable for beginners in STEM learning. mBot is easy to assemble and works together with mBlock, a graphical program inspired by Scratch 2.0 to provide hands–on experience with programming, electronics, and robotics. Drag–and–drop graphical programming software, mBlock, enables hardware connectivity to provide a quick and easy way to learn programming through robot control and interactions.

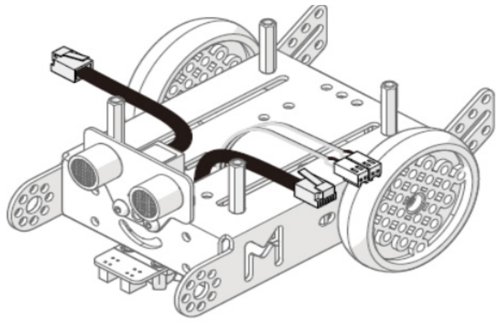

Figure 3. mBot Educational Robot

LEGO Mindstorms

LEGO Mindstorm kit is developed to allow learners to build customizable, programmable robots while teaching the principal concepts of physics, mathematics and engineering. It is a programmable teaching tool which was designed through inspiration by Piaget’s theories of cognitive development (Piaget & Inhelder, 1966).

Programming Mindstorms robot is done via a flowchart language called Robolab, based on a language called LabVIEW. The programming structure simulates a flowchart design icon by icon and allows the robot to perform different operations autonomously. The graphical approach allows students to build programs by dragging and dropping virtual representations of various operations such as moving, braking, or rotating an arm attached to a motor. The iconic blocks are then connected via a virtual “wire”. The program created via the graphical sequence of operations is then uploaded to the brick and the robot performs the commands as programmed (Chetty, 2015).

There are two generations of Mindstorms currently in use: NXT (second generation) and EV3 (third generation) (Figure 4). Major NXT parts are orange and EV3 parts are red. EV3 software is compatible with the NXT parts with a few exceptions (Valk, 2014).

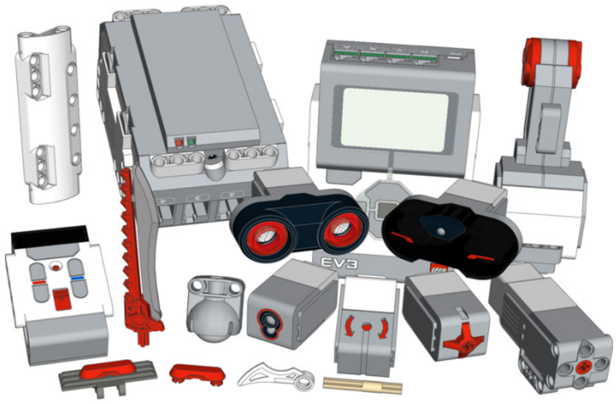

Figure 4. LEGO Mindstorms EV3 Kit

Laser Cutting

Laser cutting is a technology that uses a laser to cut materials for industrial manufacturing applications. A laser cutter uses a coherent beam of light to cut material, most often sheet metal, but also wood, diamond, glass, plastics and silicon (Figure 5). The beam is directed through a lens via mirrors or fiber optics. The lens focus on the beam at the work zone to burn, melt or vaporize the material. Exactly which process the material undergoes depends on the type of laser cutting involved.

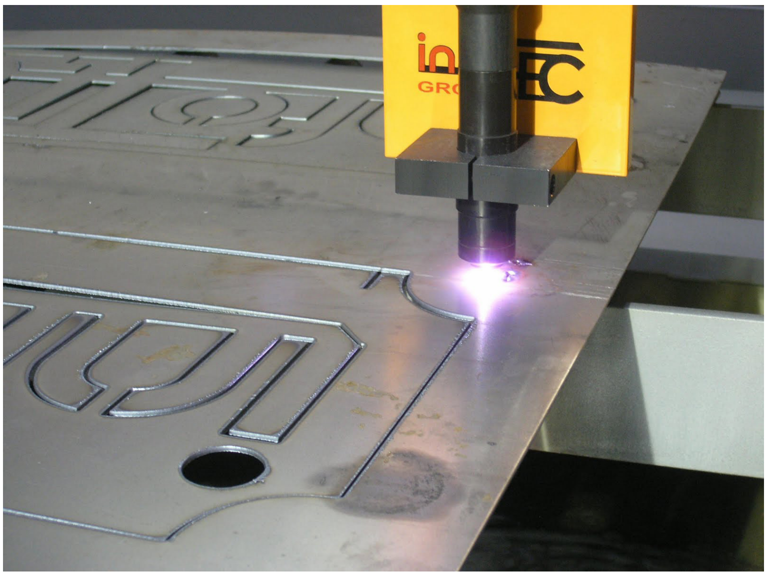

Figure 5. Laser Cutting Machine

Laser cutting can be divided into two types: laser fusion cutting and ablative laser cutting. The former involves melting material in a column and using a high–pressure stream of gas to shear the molten material away, leaving an open cut kerf. In contrast, the latter removes material layer by layer using a pulsed laser, which is like chiseling, only with light and on a microscopic scale. This generally means evaporating the material, rather than melting it (Wright, 2018).

Laser cutting allows schools to bring hands–on interactive technology to a lab or makerspace. The laser cutting brings engagement to all students, regardless of age, gender and interests.

Arduino

The origin of Arduino comes from Ivrea, Italy in 2005. The aim is to support students in their projects in order to create a cheap and efficient prototyping. The Arduino developer group led by Massimo Banzi and David Cuartielles decided to name the project prototype after a historical character named "Arduin of Ivrea". "Arduino" is the Italian version of the name, meaning "strong friend" (Wheat, 2011).

Arduino is an open–source electronics platform based on easy–to–use hardware and software. It is intended for anyone making interactive projects. It provides a simple way to learn how to program microcontrollers to sense and react to events in the real world. Its software is written in C or C++ programming language. The Arduino development board is an implementation of wiring, a similar physical computing platform, which is based on the processing multimedia programming environment (Arduino, 2011). Basic model of Arduino is shown in Figure 6.

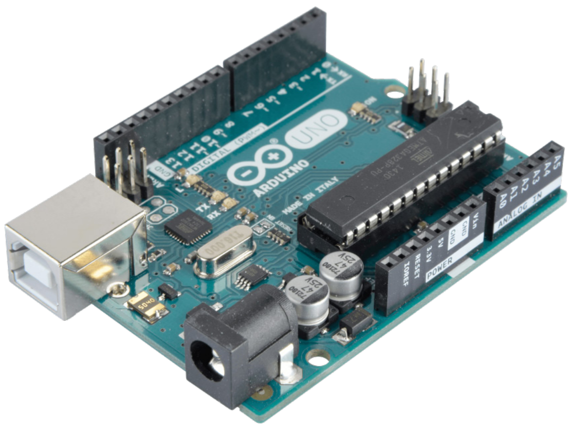

Figure 6. Basic Arduino Set

Arduino consists of many sensors in order to receive inputs from its environment and allows the user to control lights, motors and other actuators. It is an easy tool to be used by students without a background in electronics and programming. Arduino IDE is programming environment that allows the user to draft different kind of programs and load them into the Arduino microcontroller (Banzi, 2011).

Makey Makey

The Makey Makey is a microcontroller that has been pre–programmed. It connects to your computer via USB and has a range of standard keyboard inputs (space, arrows, click, etc). The Makey Makey interprets basic electronic connections as inputs and sends these signals to your computer as keyboard inputs. It is a circuit board that allows users to connect everyday objects to computer programs using alligator clips and a USB cable (Figure 7). The board uses closed loop electrical signals to send the computer either a keyboard stroke or mouse click signal.

Makey Makey is part of a creative and technological downshift in which very smart electronics are simplified to make the world manipulable by ordinary people in ways previously available only to developers. It is an invention kit that encourages people to find creative ways to interact with their computers, by using everyday objects as a replacement for keyboards and mice. Makey Makey is a useful, hands–on learning technology tool for learners of all ages, regardless of their academic strengths or weaknesses. Students can create anything from works of art to game controllers and more. Scratch is a drag and drop interactive programming interface that allows students to create interactive stories, animations, and games and interfaces with Makey Makey.

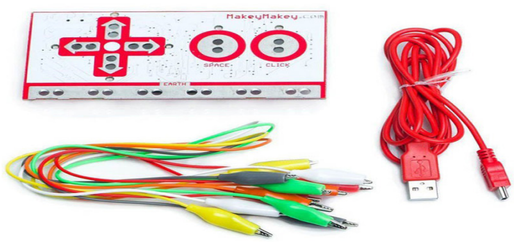

Figure 7. Make Makey Kit

Raspberry Pi

The Raspberry Pi is a low cost, credit–card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It is a capable little device that enables people of all ages to explore computing, and to learn how to program in languages like Scratch and Python. It was originally designed for education, inspired by the 1981 BBC Micro. Its creator Eben Upton's goal was to create a low–cost device that would improve programming skills and hardware understanding at the pre–university level. But, thanks to its small size and accessible price, it was quickly adopted by tinkerers, makers, and electronics enthusiasts for projects that require more than a basic microcontroller (such as Arduino devices) (Figure 8). Raspberry Pi can be utilized as a STEM tool for students to learn programming and coding because everything around them is more or less computerized in some or the other way. Therefore, Raspberry Pi can help students make interesting STEM projects by making a replication of computing machine that they see around them or do it yourself projects. STEM education aims at teaching students the concept behind things they see in their day–to–day life. One of the most common things students observe is the weather. Sunlight, rain, snow – all of these become a thing of curiosity. Raspberry Pi box can be converted into a small weather station using Python programming that enables interacting with the USB connected weather stations. Thus, teachers can enrich the world of STEM education by encouraging students to make rather than only observe.

Figure 8. Raspberry Pi Microcontroller

Drones

Unstaffed flying objects, unmanned aerial vehicles, remotely piloted aircraft. These are all alternative names for drones. Drones or Unmanned Aerial Vehicles (UAVs) have been used in the military since at least 1849. However, the development of lightweight materials improved communications technologies and decreasing costs have made drones more accessible and affordable to the educational use. These factors have also allowed drones to be used for a variety of purposes outside the military, including aerial surveillance, monitoring, deliveries and STEM education.

How do drones can be utilized in STEM education? Students may learn programming drones for a specific purpose. They can work on about how fast the drone would go with the coded instructions with factors such as calculating if there was wind on the day, what the potential wind resistance would be. They test the manual flight of the drones, so they can get an idea of how the flight dynamics and pattern of flying work for them.

One of the best ways to use drones in the classroom is to have students design and build their own drone as a class project. Making drones in the classroom may teach students to learn about robotics, math, electronics, chemistry, programming, and hands–on experience. Furthermore, students acquire the analytical thinking skills needed to understand how many different disciplines function together. Thermographic cameras are helping students studying courses related to photography, media and entertainment in nighttime scenarios.

The incorporation of thermal imaging in drones may improve learning in dark. Student may use drones to collect samples from the locations where they may not reach or go due to health risks, geological barriers. They may track wild or sea animals to identify them in the wild and track their movements from above.

Figure 9. An Educational Drone

Scratch

Scratch is a computer–coding tool designed to increase digital literacies promoting technological careers for students. It is a free visual programming language developed by the Lifelong Kindergarten group at the MIT Media Lab (Resnick et al., 2009). Scratch was developed for young people develop their visual programming language made up of block code which they drag to the workspace to animate sprites. Students can complete a range of projects including programming and sharing interactive stories, games, and animations.

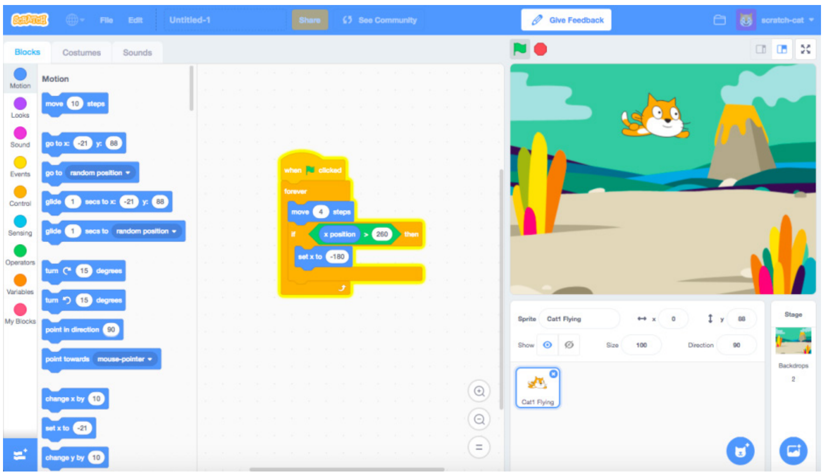

Figure 10. Screenshot of Scratch

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The Rise of Engineering in STEM Education: The "E" in STEM

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Introduction

Science, technology, engineering, and mathematics are central to many countries' focus on education and workforce development. Hence, educational systems worldwide are moving towards a more integrated vision of STEM education. By bringing together the silos of several disciplines, STEM education promises to promote the critical thinking, creative thinking, and problem-solving abilities of students—not just the memorization of facts. In fact, the information and Internet age have made access to factual information so easy that the next generations need knowledge and skills beyond knowing facts. The integration of the STEM constellation of disciplines is best accomplished through engineering, a discipline that is inherently interdisciplinary and focuses on problem solving. In this chapter, we argue that the rise of engineering in integrated STEM education will profoundly change educational systems worldwide.

Why a Focus on Integrated STEM Education?

According to the National Academy of Engineering (2014), promoting integrated STEM in K-12 education is necessary, to develop students' readiness for a STEM workforce and to promote STEM literacy regardless of whether students pursue a STEM career or not. The STEM movement arises from these two aforementioned needs which necessitate attention to both cognition and motivation. Most STEM projects aim to engage student motivation by presenting students with real-world-like problems that require interdisciplinary knowledge and abilities to solve problems—often collaboratively. During such problem-solving, students make connections among STEM disciplines, develop 21st century competencies as they think critically and creatively, and develop appreciation and interest in STEM disciplines. Hence, the STEM movement supports student engagement while promoting integration of the disciplinary content and practices of the STEM disciplines, which traditionally are taught in silos.

What is STEM?

In recent years, the term, "STEM education" has become a commonly-used term in K-12 education. According to Purzer & Sneider (2010), the initial use of the term was SMET, which was then reordered by Judith Ramaley, an NSF director from the Education and Human Resources Division as STEM. Peter Faletra, a NSF director from the Office of Science division of Workforce Development for Teachers and Scientists, has also been cited as an influential person in the transition from SMET to STEM. While driven by a common set of goals stated above, there are various definitions and models of STEM education in the literature.

Some definitions of STEM are based on the content and whether the emphasis of a specific discipline is supported by others, or by the order in which the disciplines occur as part of a curriculum. Traditionally, for many educators STEM was equated with science and mathematics, while engineering and technology take smaller supporting roles (Bybee, 2010). Bybee argues that a true STEM education integrates all four disciplines and must introduce engineering to promote problem-solving and innovation, stating that, "Given its economic importance to society, students should learn about engineering and develop some of the skills and abilities associated with the design process" (p. 996).

Another group of definitions of STEM focus on curriculum and instruction. For example, according to Moore and colleagues (2014), integrated STEM education is an approach to curriculum design that combines some or all of the four disciplines of STEM into a unit or lesson by connecting the disciplinary subjects with real-world problems.

Alternatively, Kelley and Knowles (2016) define integrated STEM education as an approach to teaching the STEM content from two or more STEM domains with a focus on students' use of disciplinary practices and the applications of STEM content through an authentic context.

What is the Role of Engineering in Integrated STEM Education?

Engineering, with its interdisciplinary nature and its focus on problem solving, is the most natural anchor for STEM integration. The discussion of engineering as a core subject in K-12 education has emerged in 2009 by a report published by the National Academy of Engineering (*Engineering in K-12 education: Understanding the status and improving the prospects*) and followed by many others (see Figure 1). Recognizing the importance of engineering and technology, the National Assessment Governing Board has developed and implemented the TEL assessment in 2014 for the assessment of technology and engineering education in the U.S. (See https://nces.ed.gov/nationsreportcard/tel).

Similarly, published in 2012, *A Framework for K-12 Science Education* (2012) integrates science and engineering while heavily influencing the development of the Next Generation Science Standards (NGSS) (Achieve, 2013).

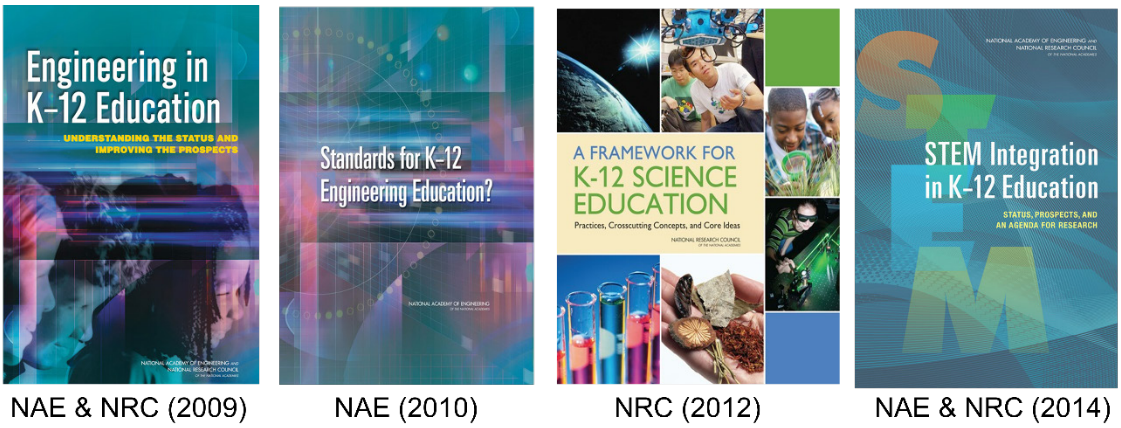

Figure 1. A Chronological Perspective of Policy Movements in Engineering and STEM in the United States

As illustrated in Figure 2, we conceptualize the role of engineering within STEM as subsuming the processes, models, and societal impact of each of the other three STEM components. Engineering, driven by problem-solving and innovation, uses scientific knowledge and models from science, technological tools and prototype modeling methods from technology, and mathematical analysis and models from mathematics.

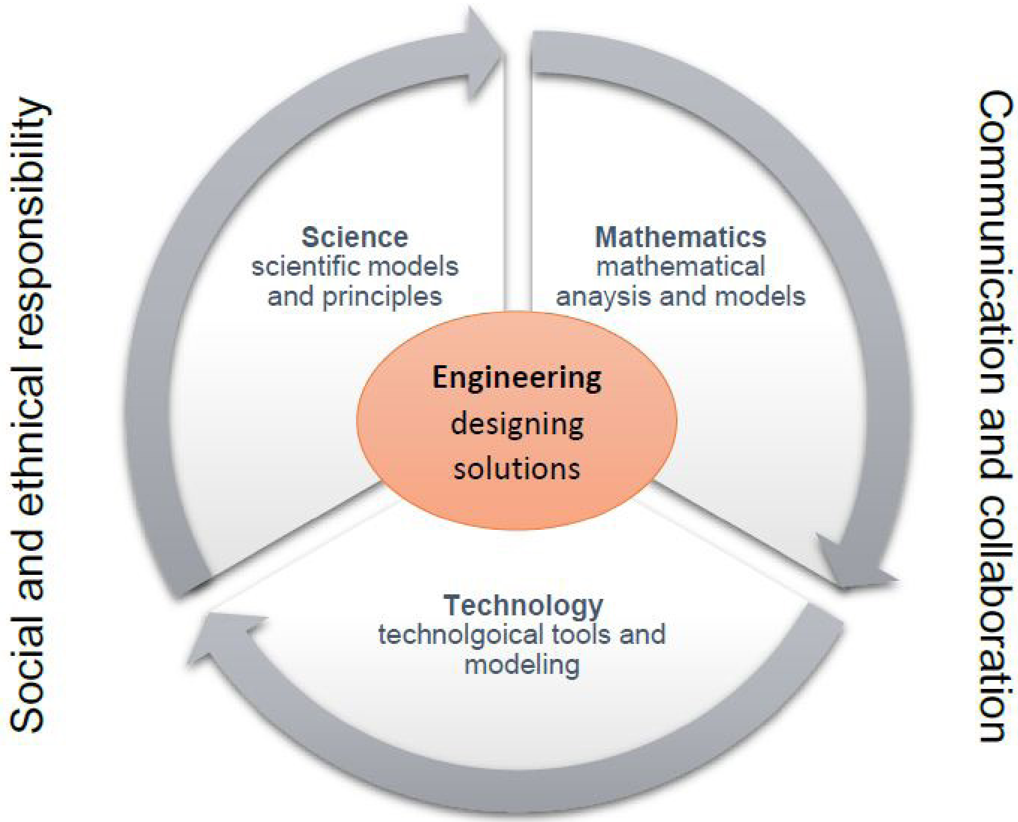

Figure 2. Engineering as an Integrator of STEM Disciplines

Engineering involves more than simply applying knowledge of mathematics, science, and engineering. Similar to science, engineering also involves designing and conducting experiments. Engineers do not only design artifacts but also systems, components, or processes to meet desired needs of users and clients. Engineers work closely with others requiring abilities to communicate well and function on multidisciplinary teams. Moreover, beyond having abilities necessary to meet technical specifications, engineers also carry professional and ethical responsibility and understand their decision can impact people, their environment, and the economic wellbeing of their organizations.

It is important to note that not all design is contained within the discipline of engineering. Engineers share this creative endeavor with many other design professionals, ranging from fashion and graphic designers to architectural and industrial designers (Fosmire & Radcliffe, 2013). Engineering differs from other design disciplines with its STEM-focus and differs from other STEM disciplines with its purpose (that is, the questions that engineers address) and its focus on constraints and trade-offs. For example, there are differences in the questions raised by scientists and questions raised by engineers. Examples include:

> Scientist: Why does an apple decompose?
>
> Engineer: How can we maintain freshness of the apple for longer periods of time?
>
> How can we reuse, reduce, or recycle agricultural waste?
>
> Scientist: How does energy transform from one form to another?
>
> Engineer: How can we effectively use solar energy to generate power?
>
> Scientist: Why do we see different phases of the moon?
>
> Engineer: How do we get to the moon?

If we take any of these questions with the viewpoint of the engineer, we would find that the solution would require an exploration or an understanding of the scientific question but also more. The engineer must also understand the context from whence the problem has emerged, define design specifications (criteria and constraints), generate a variety of solutions to select from, and make trade-off decisions as engineering does not involve a correct solution but one that satisfies the needs of the user or client.

STEM Education in the United States

In 2015, in the United States 91% of young adults ages 25 to 29 had a high school diploma or its equivalent, compared to 83% for OECD countries overall, and 36% had a bachelor's degree or higher. Further, 46% had an Associate's degree or higher (compared to 41% for OECD countries), 36% had a Bachelor's degree or higher, and 9% had a Master's degree or higher. In school year 2013–14, 82% of public high school students graduated with a regular diploma, with 68% of 2014 high school completers enrolled in college the following fall, of which 44% went to 4-year institutions and 25% went to 2-year institutions. In contrast, OECD (2018) reports that tertiary educational attainment for Turkey in 2016 of 19%, a tertiary graduation rate of 69%, and 70% of those aged 15-19 are enrolled in secondary education.

The United States has a large pipeline of students potentially headed for higher education. Public school enrollment in 2013–14 was 50.04 million, with 35.25 million in prekindergarten through grade 8 and 14.79 million in grades 9 through 12. An additional 5.4 million students were enrolled in private schools in 2013–14, of which 4.1 million were in prekindergarten through grade 8 and 1.3 million in grades 9 through 12. Overall, about 9.7% of all students in the United States are enrolled in private schools.

Higher education in the United States in Fall 2014 included total enrollment of 17.29 million, 10.78 million of whom were enrolled full-time and 6.51 million enrolled part-time. A larger fraction (28%) were enrolled in at least one distance education course, and 12% were enrolled exclusively in distance education.

Postbaccalaureate enrollment in the United States in Fall 2014 included total enrollment of 2.91 million, of whom 1.67 million were enrolled full-time and 1.24 million were enrolled part-time. Of graduate enrollment, 33% were taking at least one distance education course and 25% were enrolled exclusively in distance education.

Some countries generate a large number of degrees in engineering. Using the United States as a case in point, in 2013-2014 31,800 associate's degrees in engineering were conferred by postsecondary institutions (compared to 36,900 in 2003-2004), 99,000 bachelor's degrees in engineering were conferred (compared to 73,000 in 2003-2004), 42,400 master's degrees in engineering were conferred (compared to 32,600 in 2003-2004), and 10,000 doctoral degrees in engineering were conferred (compared to 3,800 in 2003-2004).

The higher education system in the United States is huge, providing for a wide variety and large numbers of different types of institutions, many of which offer degrees in engineering.

In 2013-2014 the total number of postsecondary institutions was 7,236, of which 4,724 are degree-granting; of the degree-granting institutions 1,685 are 2-year institutions and 3,039 are 4-year institutions. Many of these higher education institutions in the United States provide degrees in engineering. In 2013-2014, 345 institutions offered an associate's degree in engineering, 519 offered a bachelor's degree in engineering, 318 offered a master's degree in engineering, and 215 offered a doctoral degree in engineering. Also, 1,160 institutions offered an associate's degree in engineering technologies and engineering-related fields; with 404 offering bachelor's degrees, 176 offering master's degrees, and 18 offering doctoral degrees in this area.

The higher education pipeline in engineering clearly requires students who receive adequate training in secondary or elementary levels (e.g., Park, Yoon, Hand, Therrien, & Shelley, 2013a, 2013b, 2013c; Schoerning, Hand, Shelley, & Therrien, 2015; Villanueva, Hand, Shelley, & Therrien, forthcoming). Knowing when students have achieved an appropriate level of skill in engineering is not simple to ascertain. A key concern is how to assess student competencies in engineering. One immediate difficulty is that engineering is multidimensional and overlaps with other disciplines. Some areas, such as software engineering, can be joint programs (e.g., with the College of Liberal Arts and Sciences at Iowa State University). Engineering also is closely related to science generally and specific areas of science such as physics. The necessity for success as engineering undergraduates is that students do well in physics, calculus, and other STEM courses closely related to engineering (Laugerman & Shelley, 2013; Laugerman, Shelley, Mickelson, & Rover, 2013; Rover, Mickelson, Hartmann, Rehmann, Jacobson, Kaleita, Shelley, Ryder, Laingen, & Bruning, 2014; Laugerman, Shelley, Mickelson, & Rover, 2013; Laugerman, Rover, Shelley, & Mickelson, 2015; Laugerman, Rover, Mickelson, & Shelley, 2015; Laugerman, Rover, Mickelson, & Shelley, forthcoming-a, forthcoming-b). What it takes for students to flourish in engineering classes, and in particular the appropriate application of scaffolding, have been addressed by Boylan-Ashraf, Freeman, and Shelley (2015) and Boylan-Ashraf, Freeman, Keles, and Shelley (2017).

Measurement of Student Learning— Can PISA data inform STEM learning outcomes?

A fuller appreciation of the measurement of student learning and of the universality of interest in STEM learning outcomes requires a global perspective. It is important to recognize and make optimal use of the trans-national nature of research on education (Shelley, Yore, & Hand, 2009). By comparing student performance across counties, such research can inform public policy and help countries strive for and achieve the high-quality education necessary for workforce development and economic growth.

Although Engineering clearly is included in the definition of STEM, it is not addressed as clearly as Science and Mathematics, or Reading, in leading assessments of student performance such as PISA (Programme for International Student Assessment http://www.oecd.org/pisa/). Because of its comprehensive approach, we concentrate here on PISA, which is sponsored by the Organization for Economic Cooperation and Development (OECD) headquartered in Paris, France. The 2015 study is the latest available from PISA; a new wave of data is being collected in 2018.

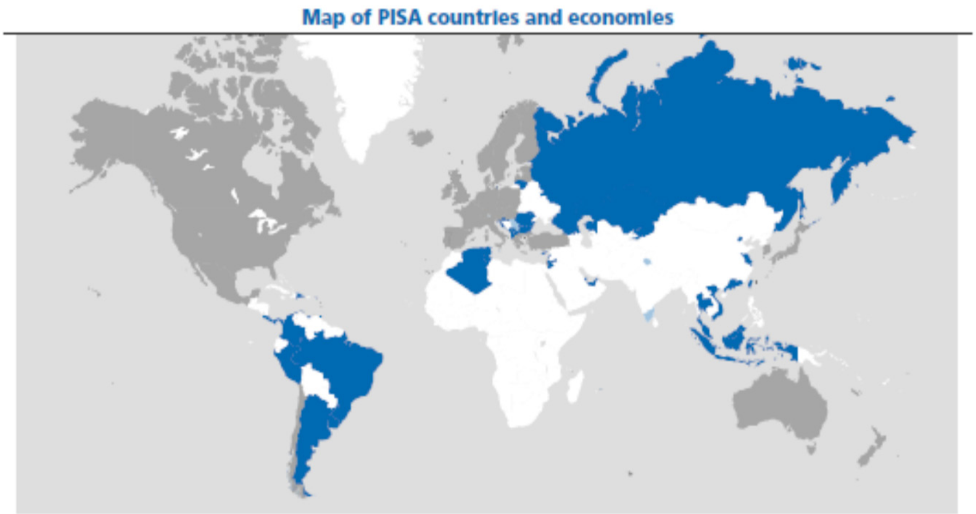

Figure 3. Map of PISA Countries and Economies, 2015 (OECD, 2016, p. 27)

We argue that PISA data with its focus on science, mathematics, literacy, and problem solving can be used to evaluate key aspects of STEM literacy. The Organization for Economic Cooperation and Development (OECD) is composed of 35 counties (as the gray text in Figure 3 shows). In 2015, an additional 37 non-OECD countries and economies also participated in PISA (see blue text in Figure 3). Figure 4 lists these countries and economies as well as partner countries and economies that have participated in earlier waves of PISA prior to 2015.

OECD countries		Partner countries and economies in PISA 2015		Partner countries and economies in previous cycles
Australia	Korea	Albania	Lithuania	Azerbaijan
Austria	Latvia	Algeria	Macao (China)	Himachal Pradesh-India
Belgium	Luxembourg	Argentina	Malaysia	Kyrgyzstan
Canada	Mexico	Brazil	Malta	Liechtenstein
Chile	The Netherlands	B-S-J-G (China)*	Moldova	Mauritius
Czech Republic	New Zealand	Bulgaria	Montenegro	Miranda-Venezuela
Denmark	Norway	Colombia	Peru	Panama
Estonia	Poland	Costa Rica	Qatar	Serbia
Finland	Portugal	Croatia	Romania	Tamil Nadu-India
France	Slovak Republic	Cyprus[1]	Russian Federation	
Germany	Slovenia	Dominican Republic	Singapore	
Greece	Spain	Former Yugoslav Republic of Macedonia	Chinese Taipei	
Hungary	Sweden	Georgia	Thailand	
Iceland	Switzerland	Hong Kong (China)	Trinidad and Tobago	
Ireland	Turkey	Indonesia	Tunisia	
Israel	United Kingdom	Jordan	United Arab Emirates	
Italy	United States	Kazakhstan	Uruguay	
Japan		Kosovo	Viet Nam	
		Lebanon		

Figure 4. List of PISA Countries and Economics, 2015 (OECD, 2016, p. 27)

PISA tests are administered every three years. The emphasis of the tests varies among science, mathematics, and reading; it is important to note that there are no PISA test items related to engineering (nor none directly related to technology), although the 2015 PISA data do include problem-solving, which is closely aligned with the STEM movement. The 2015 PISA round was focused on science.

Data were collected from about 540,000 15-year-old students in 72 countries and economies, who were tested on science, reading, mathematics, and collaborative problem-solving. Table 1 presents information about PISA scores and wealth measured in GDP per capita for a selected set of countries that are the focus of subsequent discussion. Singapore ranks at the top among nations and economies in PISA results, the United States is roughly in the middle, Turkey ranks among the lower-performing countries, and Tunisia is representative of the lowest-performing countries on PISA metrics. There is a clear relationship between higher PISA scores and higher per capita gross domestic product (GDP).

Table 1. PISA Scores Compared to Economic Development for Selected Countries

Country	**PISA Scores Science/Reading/Mathematics/Problem-solving**	**GDP per capita (in $US) (NationMaster.com)**
Singapore	556/535/564/561	$51,709
United States	496/497/470/520	$49,965
Turkey	425/428/420/422	$10,666
Tunisia	386/361/367/382	$4,236

PISA assesses the extent to which students who are near the end of their compulsory education have acquired key knowledge and skills essential for full participation in modern societies. The assessment focuses on the core school subjects of science, reading, and mathematics. Students' proficiency in an innovative domain is also assessed (in 2015, this domain was collaborative problem solving). The assessment does not just ascertain whether students can reproduce knowledge; it also examines how well students can extrapolate from what they have learned and can apply that knowledge in unfamiliar settings, both in and outside of school.

This approach reflects the fact that modern economies reward individuals not for what they know, but for what they can do with what they know. PISA is an ongoing program that offers insights for education policy and practice, and that helps monitor trends in students' acquisition of knowledge and skills across countries and in different demographic subgroups within each country. PISA results reveal what is possible in education by showing what students in the highest-performing and most rapidly improving education systems can do. The findings allow policymakers around the world to gauge the knowledge and skills of students in their own countries in comparison with those in other countries, set policy targets against measurable goals achieved by other education systems, and learn from policies and practices applied elsewhere. While PISA cannot identify cause-and-effect relationships between policies/practices and student outcomes, it can show educators, policymakers, and the interested public how education systems are similar and different, and what that means for students (http://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf).

The primary public policy purpose of the PISA measurements of student achievement is to provide information about workforce development and economic growth based on secondary-school-level educational attainment of concepts and applications. There is a strong emphasis on equity, and on policies and procedures to help countries achieve high-quality and efficient schools. In the 2015 PISA data, Singapore outperformed the rest of the world; the top OECD countries in terms of student achievement were Japan, Estonia, Finland, and Canada.

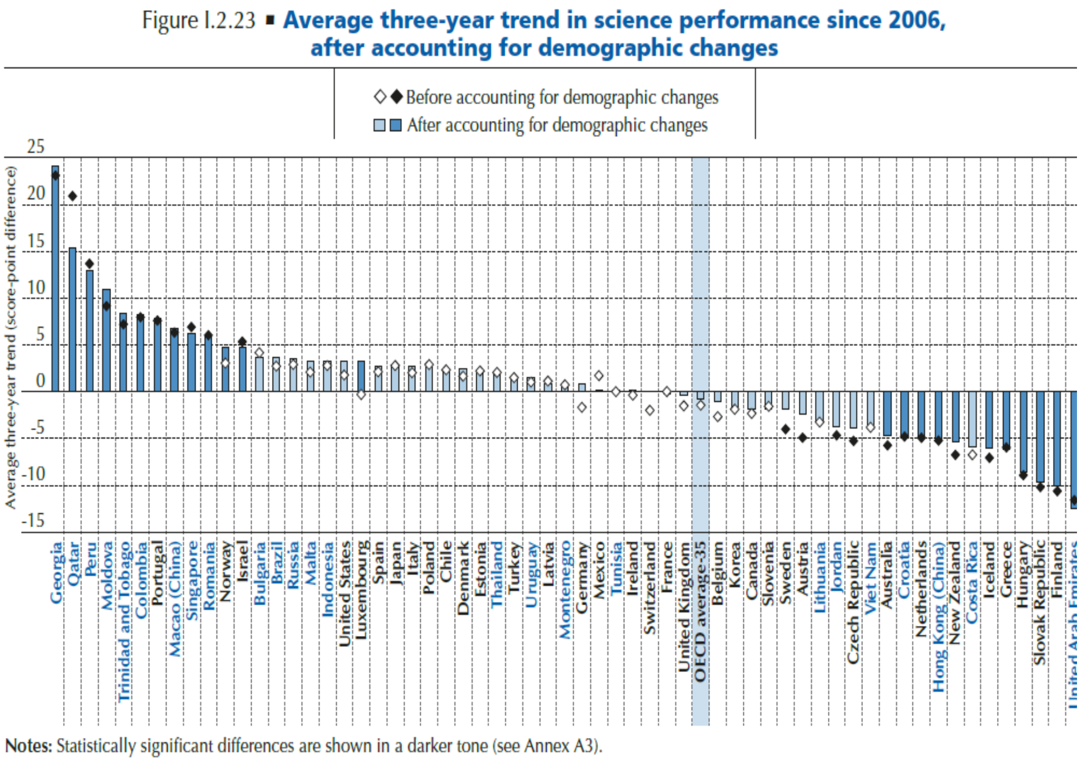

Figure 5. Gains in PISA Science Scores Between 2006 and 2009, Before and After Accounting for Demographic Changes (OECD, 2016, p. 86)

Mean student test scores for the PISA 2015 results in Science were 493 for all OECD countries combined, 425 for Turkey, and 496 for the United States. In Reading, the mean OECD score was 493, with 428 for Turkey and 497 for the United States. The OECD mean Mathematics score was 490, as compared to 420 for Turkey and 470 for the United States. Relationships among PISA Science, Mathematics, and Reading scores in Turkey have been explored (Shelley & Yildirim, 2013).

In Chile, Denmark, Mexico, Slovenia, Turkey, and the United States, between 2006 and 2015, students' socio-economic status became less predictive of performance and weakened in its impact on performance, while these countries' average level of achievement remained stable.Gains were made in many countries in science, taking into account demographic changes that occurred in that decade (see Figure 5).

Four Components of STEM Learning Measured by PISA

PISA scores provide an interesting opportunity in examining STEM learning outcomes from the perspective of four variables: collaborative problem-solving, scientific literacy, mathematical literacy, and reading performance. If STEM education efforts are effective, we would expect students to grow in these four aspects. To illustrate rate this, we use radar graphs to show PISA scores in science, mathematics, problem solving, and reading for Singapore (a high-performing country), the United States (average), Turkey (low performer), and Tunisia (one of the lowest performing countries) (see Figure 6).

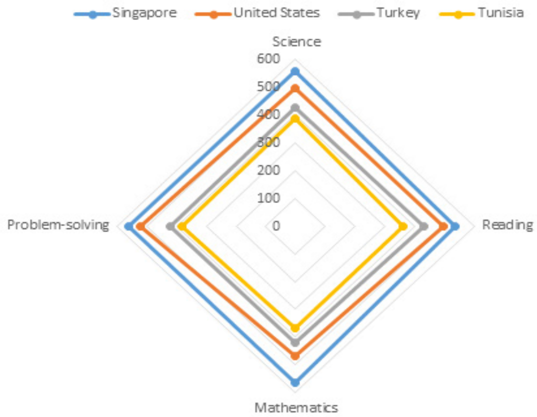

Figure 6. Comparing Four Countries on PISA 2015 Outcomes

It is evident (Figure 6) that a country that is lower on one of the four outcomes also is lower on the other outcome metrics. Also evident is that each country has a unique pattern of student outcomes (See Figures 7). Singapore excels in all areas but comparatively less so in reading. United States students do best in problem-solving and comparatively much less well on mathematics. Turkish students do best on reading and comparatively more poorly on mathematics and problem-solving. Students in Tunisia do relatively better on problem-solving and science, but are very low on all metrics compared to global norms.

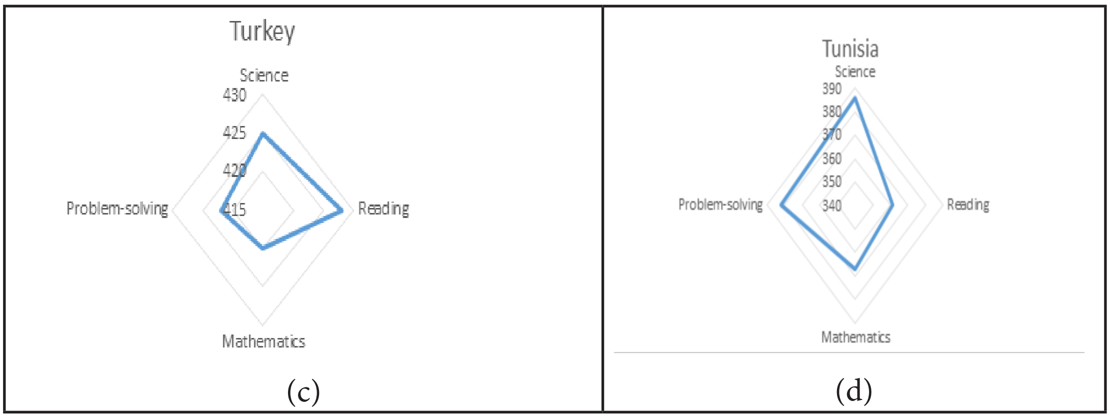

Figure 7. PISA 2015 Outcomes for Singapore, United States, Turkey, and Tunisia

While traditionally the PISA scores have been used to compare countries, and the motivation from such competition has been used to inform policy changes for better education, each country can also use the PISA scores examine their specific STEM motif and build on their strengths. In Figures 7a, 7b, 7c, and 7d, we illustrate the respective strengths and weaknesses on four dimensions of PISA for four countries. For example, based on this visualization, we recommend that the United States can leverage its strength in collaborative problem-solving to better integrate science, mathematics, and literacy. STEM curricula can be developed with a focus on problems, while making the application of science and mathematics concepts explicit using instructional models such as Learning by Design (Kolodner 2002; Kolodner et al, 2003). Turkish educators can explore integrating their STEM education in closer alignment with reading, which is their strongest dimension.

Instructional approaches such as Novel Engineering, developed by researchers at Tufts University might be applicable (McCormick & Hammer, 2016). In Novel Engineering, students read books, identify the needs of a book character, and design solutions to meet the needs of book characters.

Measurement of Student Learning—Can we assess integrated learning outcomes?

While the promise of STEM education is significant in both promoting student engagement and learning outcomes associated with knowledge and practices, assessment in such rich learning environments is a challenge. The essential components of integrated assessment (see Figure 8) require that it emphasizes the multidimensionality of learning, the requirement that assessment be sensitive to what students are learning but at the same time allow transfer abilities, provide reliable and fair measures of student learning, allow for differentiation across STEM areas and across students, and have educational value (Purzer et al., 2016).

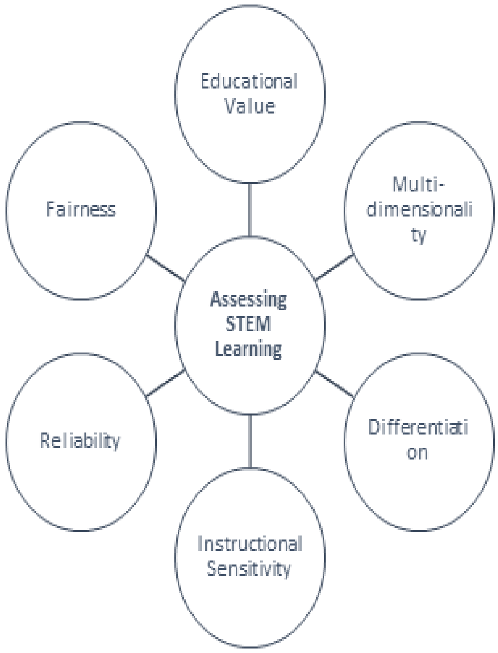

Figure 8. Framework for Integrated Assessment

While the requirements may seem lofty for what an effective assessment must entail, the use of performance assessments can help measure multiple aspects of learning. However, research on performance assessment in integrated STEM is not well-studied in the literature. Caution must be taken in several ways. In struggling to establish appropriate criteria for evaluating student proficiency in engineering, it is common to encounter what we can refer to as "myths" of engineering education assessment.

The overarching myth is the belief that the concepts of validity, reliability, and fairness are meant only for psychometricians and do not apply to classroom assessment in engineering. Related to this overarching myth are three specific myths:

- Myth #1: Student-designed prototype performance is a reflection of student (science) learning.
- Myth #2: Rubrics designed specific to projects are a sign of best practices.
- Myth #3: Assessment is not appropriate in project-based or integrated STEM because tests are not appropriate and engagement means learning.

Myth #1: Student-designed prototype performance is a reflection of student (science) learning.

There is much more to students' performance in design than simply a reflection of their learning from science. Students must be able to address multiple design goals simultaneously that both apply and transcend learned science knowledge.

For the Energy3D Software project (http://energy.concord.org/energy3d/), students concurrently were striving to achieve net zero or positive energy, minimize cost of the project, provide a house large enough for a family of four, and design a structure with curb appeal that would elicit positive reactions from those who viewed the house.

Energy3D is a simulation-based engineering tool for designing green buildings and power stations that harness renewable energy to achieve sustainable development. Users can quickly sketch up a realistic-looking structure or import one from an existing CAD file, superimpose it on a map image (e.g., Google Maps or lot maps), and then evaluate its energy performance for any given day and location. Based on computational physics and weather data, Energy3D can rapidly generate time graphs (resembling data loggers) and heat maps (resembling infrared cameras) for in-depth analyses. At the end of the design, Energy3D allows users to print it out, cut out the pieces, and use them to assemble a physical scale model. Energy3D has been developed primarily to provide a simulated environment for engineering design (SEED) to support science and engineering education and training from middle schools to graduate schools (Chao et al., 2017).

There is considerable value-added when students conduct systematic experiments. Student practices related to experimentation such as conducting more experiments (overall) and conducting more systematic experiments are associated with higher levels of performance in strategic design knowledge and science learning gains (Vieira, Goldstein, Purzer, & Magana, 2016; Chao et al, 2017).

Hence, we argue that rather than assessing the performance of student-designed prototypes, instructors should use these prototypes to elicit students' justification of design features and explanations of results from their experimentation.

Hence, rather than a narrow focus on evaluations of the performance of student prototypes, teaching and assessment practices should emphasize student justification of their design decision and reflective design practices.

Myth #2: Rubrics designed specific to projects are a sign of best practices.

While rubrics or assessment guides are critical for performance assessment, the utility of these tools depends on their usability across multiple projects. Hence, rubrics designed with attributes specific to a project will not be useful when it is time to evaluate a new project. Alternatively, rubrics with too broad descriptions are not useful as they will have limited utility in helping students see the specific areas in which they need to improve. Hence, we recommend designing and testing rubrics that will work across at least three projects covering overlapping learning objectives; this approach provides pertinent assessment of engineering design.

Figure 9 provides a schematic overview of the process of student assessment. The diagram outlines the iterative nature of assessment, linking the need to assess for planning, interpreting student learning, providing feedback to students, students using feedback to improve their understanding, and using assessment results to inform instruction and provide further input into planning for additional assessment.

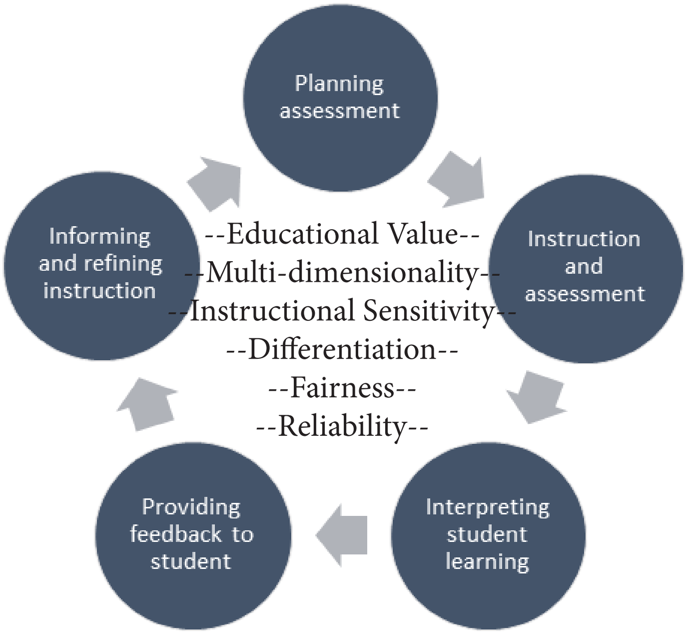

Figure 9. A Process for Pertinent Assessment

- **Step 1** is to start with specific learning goals and competencies that cut across projects. These goals may include decision-making, critical thinking, creativity, communication, and other desirable student outcomes (see Table 1). Specific performance expectations should be developed associated with each goal.

- **Step 2** is to develop analytic rubrics (scoring guides) and iteratively map rubric components to specific competencies associated with those components. In developing these rubrics it is important that performance descriptions are not too specific to a project but rather can cut across multiple projects.

- **Step 3** is to plan for and give students at least three project opportunities to demonstrate their learning. With the first opportunity, students are learning.

- With the second opportunity, students are learning what is expected and how to respond to feedback. With the third opportunity, students have gotten to the point that they can demonstrate that they have learned what is expected.

- **Step 4** is to chart individual student progress and to summarize group progress on specific goals and competencies.

Myth #3: Assessment is not appropriate in project-based or integrated STEM because tests are not appropriate and engagement means learning.

In fact, assessment of student competencies is integral to gaining a good idea of how much and how well students have learned. Several key elements in this process of assessment are presented in Table 2, with the relevant performance expectations for each assessment element.

Table 2. A sample of Critical STEM Competencies

Competency	Definition	Sample Performance Expectation
Problem Scoping	Develop a problem statement from the perspective of stakeholders. Refine the problem statement as additional information is found through the process of design.	• Ask questions relevant to the problem • Explains the problem based on synthesis of client, user, or other stakeholder needs. • Explains key design specifications (in terms of criteria and constraints) that address what the client wants and what the user needs within the problem's contextual constraints.
Evidence-Based Decision Making	Use evidence to support decisions when problem scoping, comparing alternatives, and optimizing a design solution.	• Makes explicit reference to data when explaining trends, justifying decisions, or making comparisons. • Identifies relevant assumptions needed to be made in cases when there are barriers to accessing information.
Idea Fluency	Generate ideas fluently. Take risks when necessary.	• Generates a wide range of solutions including ideas not readily obvious or combinations of ideas in new ways.
Engineering Ethics	Recognize how contemporary issues as part of cultural, economic, and environmental factors impact engineering design and practice.	• Recognizes that cultural, economic, environmental and other non-technical factors influence design decisions.
Process Awareness	Reflect on both personal and team's problem solving/design approach and process for the purpose of continuous improvement.	• Identifies strengths in problem solving/design approach clearly related to the problem. • Identifies weaknesses in the approach used, with discussion of how those limitations impact the process.
Technical Communication	Communicate engineering concepts, ideas, and decisions effectively and professionally in diverse ways, such as written, visual, and oral.	• Presents all visual representations (figures, images, sketches or prototypes) with high technical quality, labeling key components to show their form and function. • Communicates professionally using scientific and technical vocabulary.
Teamwork	Contribute to team products and discussions	• Contributes to the team tasks and discussions.

Conclusion

As countries all over the planet focus on STEM education initiatives and seek stronger economic growth through workforce development, the need to integrate the elements of STEM becomes increasingly important. Concurrent with that integrative imperative is the need to incorporate Engineering more directly into the STEM constellation alongside Science, Technology, and Mathematics. Both goals can be achieved most functionally by recognizing and making use of the inherently integrative nature of Engineering. A more prominent role for the "E" in STEM will yield benefits for each of the Science, Technology, and Mathematics moving parts that constitute the constellation. Related to the integration of Engineering is the need for accountability in conducting assessments of the effect of engineering curricular innovations on student outcomes. A stronger role for Engineering in STEM and its focus on problem-solving can help to close the achievement gaps in STEM and help establish the preconditions for stronger analytical skills globally.

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Mathematics (M) in STEM

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Nowadays STEM is one of the hot topics in our world. On the one hand most of the readers know that STEM stands for science, technology, engineering, and mathematics, on the another hand they probably agree on the equally importance of each subject for human beings. However for some of us (i.e. mathematics educators), one letter, which is M, is more salient than others. Especially in STEM education “what is the meaning of mathematics?” is a crucial question, which will be discussed in the rest of this chapter.

Definitions of M in STEM could have different meanings for individuals. Clark-Wilson and Ahmed (2009) stated this difference as how M in STEM should be interpreted; it could be increasing the achievement in mathematics or including mathematics in an integrated curriculum. The former allows us to segregate mathematics but the latter requires interwoven structure, which would be more proper to indicate as M in STEM. Therefore, it would be fair to state that mathematics in STEM should be used more than a service subject for the other three subjects (Clark-Wilson & Ahmed, 2009).

Mathematics could be accepted as an essential subject for many, and for mathematics teachers it is serious and valuable subject because it provides a connection between subjects. However mathematics teachers had some concerns about understanding the significance of “mathematics” by others. In fact, Coad (2016) reflected teachers’ opinions in his paper where he gathered and presented their ideas emerged from a meeting (i.e., workshop). These reflections were as follows: 1) to use mathematics as a data presentation tool can result in discrediting mathematics; 2) do not expect students to understand every detailed mathematical procedure in STEM activities yet accept mathematics as a part of STEM projects; 3) mathematics is inevitable component of STEM activities; 4) assessing mathematical achievement and engagement is important; 5) the difficulty of differentiation of mathematical outcome in STEM activities. Also Clark-Wilson and Ahmed (2009) focused on determining mathematics teachers’ practices, who involved in STEM collaborative professional development (CPD) projects, by examining their perceptions about M in STEM and exploring what makes rich STEM CPD and how mathematics was defined in STEM. The results were that there should be definitely a shared vision and pedagogy about mathematics in STEM. In addition to that developing the view of using mathematics to a broader perspective was another result. One of the concerns was also giving each subject an essential importance and keeping their integrity as well. Difficulty of preparing authentic mathematical activities without focusing only about the content with concerns was another problem. These reflections and results revealed that mathematics’ role in STEM was not crystal clear, which is understandable because I believe mathematics' role in STEM is not just about only being a subject it also has different roles. Even though mathematics as an academic subject is not included in a STEM activity, this does not mean it is not included because from my standpoint M in STEM also means "mathematical thinking and understanding", "mathematical problem solving", "mathematical reasoning", and " mathematical modelling".

Mathematical Thinking and Understanding

Instead of teachers teaching students any rule about any subject with rote memorization, teaching them a style of thinking is in need of today's world (Winchester, 2007). Mathematical thinking is a style of thinking that is an interrogation of our world (Winchester, 2007), and therefore it is used widely in educational context. For instance, a teacher, who searched for the definition of mathematical thinking to ensure that she conveys thinking mathematically to her students, realized that the symptoms in mathematical thinking were actually "generic thinking skills and could be applied to all subjects and problems that we encounter in life" (Pitt, 2002, p. 4). This is exactly what educators are looking for in STEM projects- thinking skills required to solve real-life problems. Therefore, mathematical thinking is one of the reasons why "M" needs to be considered as an essential element of STEM.

There is not a specific and one definition of mathematical thinking (Lane, 2005; Sternberg, 1996). Researchers focused on analyzing, conjecturing, proving, reasoning, justifying, formalizing, generalizing, and advanced thinking (Ball, 2002; Dreyfus, 1990; Lane, 2005; Mason, Burton & Stacey, 2010; Polya, 1954; Selden & Selden, 2005). Sternberg (1996) addressed different explanations of mathematical thinking made by researchers, organized all approaches, and categorized these approaches as psychometric, computational, anthropological, pedagogical, and mathematical. Sternberg (1996) pointed out following abilities as mathematical thinking according to different approaches: Fluid intelligence (i.e., the importance of sequence and speed or reasoning), crystallized intelligence (i.e., the importance of knowledge and language skills), memory ability, visual apprehension (Carroll, 1996), information-processing (i.e. quantitative & qualitative reasoning) (Mayer & Hegarty, 1996), analogical thinking (Ben-Zeev, 1996), and creative thinking. Especially Ben-Zeev's (1996) explanation of mathematical thinking was dramatic because analogical thinking in mathematics occurs when "one forms a mapping between past problems one has solve and the present problem one is seeing to solve, and also when one seeks to see the relations among a set of problems one needs to solve in the present" (Sternberg, 1996, p. 307).

This explanation shows us that this style of thinking is actually what commonly used in STEM projects or challenges. Starting from this point of view, it would be unfair not to state the mathematical thinking as a part of STEM.

Mathematical Problem Solving

STEM projects or activities start with a problem, which can be real-life problem or a problem expecting to motivate students and brought to class by teacher. The very first step of STEM activities is to understand or determine the problem, which is the foundation of other steps. Lack of depth and comprehensive understanding of a problem situation could end with undesired results. Therefore, understanding the problem is essential to complete STEM projects. When this first step is ensured, changes on the rest would be acceptable with regard to situation, project, or activity, etc.

After understanding the problem, students would be expected to solve the problematic situation. Solving problem does not have to be related with mathematics because the definition of 'problem' is more generic. However, even though students do not solve any mathematical problem as content, they would still involve in problem solving process. Mathematical problem solving strategies were elaborated by Polya (1957) for mathematics: understanding problem, devising a plan, carrying out the plan, and looking back. These strategies "help an individual to understand a problem better or to make progress toward its solution" (Schoenfeld, 1985, p. 23) and when these strategies are examined, they are obviously vital steps to solve any kind of given problem. Thus, when students actually solve any problem situation, they actually use the ability of problem solving. Therefore problem solving is an essential, unignorable, and necessary ability to be used during STEM projects.

Mathematical Reasoning

In STEM practices, mathematical knowledge and understanding are inevitable elements. Reasoning -a component of these elements- was stated as "the principal instruments for developing mathematical understanding and for constructing new mathematical knowledge" (Ball & Bass, 2003, p. 30). The importance of reasoning was mentioned in mathematics and science standards from different aspects. For instance, reasoning and proof was one of the five process standards in Principles and Standards for School Mathematics; therefore, reasoning was emphasized several times in Common Core State Standards for Mathematics (CCSSM) as well. The idea of reasoning were also emphasized in Next Generation Science Standards Practices (NGSS) (e.g., constructing explanations and designing solutions, engaging in argument from evidence).

These standards (i.e., CCSSM and NGSS) not only shapes states' standards but also are used as resource while comparing other countries' standards. The stress on reasoning in both science and mathematics standards is an indicator of mathematical reasoning being a necessary element in STEM.

Mathematical reasoning was defined differently by researchers. Ball and Bass (2003) stated two types of reasoning: reasoning of inquiry and reasoning of justification. The former was a process when mathematical reasoning was used during exploration of new ideas and the latter was used during proving mathematical claims. Reasoning of justification in mathematics was consisted of two parts: the base of public knowledge and mathematical language (Ball & Bass, 2003). The base of public knowledge was basically defined as the knowledge known by and explicit for every individual in the community (e.g., students, teachers, mathematicians). Mathematical language was symbols, terms, representations etc. that was used to communicate in the community for clarity of mathematical ideas, claims and so on. Structural and process aspects of mathematical reasoning was elaborated in Jeanotte and Kieran's (2017) study. The structural aspects of mathematical reasoning were listed as deductive, inductive and abductive. The emphasis in these aspects were on being true, likely, or generating data and justification in the best way, respectively. Regarding process aspect of mathematical reasoning, searching for similarities and differences, validating, and exemplifying were other components (Jeanotte & Kieran, 2017). Generalizing, conjecturing, identifying a pattern, comparing, and classifying were listed as processes of mathematical reasoning related searching for similarities and differences. Validating, justifying, and proving dealt with the changing the epistemic value one way or another, modifying the epistemic value with data or support, and modifying the epistemic value with data or support from being likely to true, respectively (Jeanotte & Kieran, 2017). Lastly, exemplifying was defined as a mathematical reasoning process covers previous two process related aspects: searching for similarities and differences, and validation (Jeanotte & Kieran, 2017).

Generally as the last phase of STEM PBL activities ends with communication and reflection of students' outcomes (Capraro, Capraro, & Morgan, 2013), especially if engineering design process is followed. When students perform this last phase, they also use their reasoning ability. They need to explain their ideation and the reason why they choose to solve problem in their specific way. This process requires reasoning abilities such as justification, proving, and validation. For instance, when students were asked to explain their reasoning while solving given task, they used variety of representations such as analogy, diagrams, verbal or written statements to form conjectures, generalize, explain, validate and justify (Vale et al., 2017).

These types of representations were mostly used to perform engineering design process' steps during STEM PBL activities. Therefore, mathematical reasoning is an inevitable skill required in STEM education.

Mathematical Modelling

Mathematical modelling is almost an inevitable process in today's world. Mathematical modelling is "the process of solving problems set in the real world" (Berry, 2002, p. 214). It is actually a transition between real world and mathematics and during this transition the structure of real-life situations are probed through mathematics (Erbas et al., 2014). Researchers did not have a consensus about perspectives on this topic but they agreed on that mathematical modelling is in need when real word situation problems are solved (e.g., Berry, 2002; Blum & Borromeo Ferri, 2009; Niss, 2012).

Mathematical modelling was classified according to its usage in problem situations- as a vehicle or content. When mathematics was used as an aid to introduce or understand other curricular materials, it was used as vehicle; when mathematics was used to learn, improve and apply mathematical knowledge to solve real life problems, it would be used as content (Galbraith, 2012). In addition to that Kaiser (2005) and Kaiser and Sriraman (2006) classified different perspectives of modelling and listed as: a) realistic or applied, b) contextual, c) educational, d) socio-critical, e) epistemological and f) cognitive. Even though different explanations existed in the literature, the modelling process was defined almost similar by researchers.

Mathematical modelling process definition had variaty (Galbraith, 2012; Galbraith & Stillman, 2006; NCTM, 1989; Pedley, 2005) in literature however fundamental phases were similar and as following: 1) understanding the given situation; 2) formulating a mathematical model; 3) analyzing and solving the model; 4) comparing model with reality and validating; 5) revisiting the process if necessary. When STEM activities' design process was examined, STEM design phases included most of them (Capraro et al., 2013), so these steps are subpart of STEM design process. Therefore, even though STEM projects does not include mathematics as content in it, mathematical modelling would be part of these projects, thus 'M' would be automatically included.

Conclusion

STEM education is a popular subject for many countries, however we all know applying STEM education truly in schools require many changes. These changes extend from curriculum to teachers. When we think about all these requirements to establish well-applied STEM activities, hierarchically curriculum could be listed at the top. However it is so remarkable not to come across with connections among standards of STEM subjects in curriculum, whereas for instance most science standards already include mathematics and mathematical procedure in it. Therefore even though assuming not to include mathematics as a subject in STEM activities seems possible, when science or other two disciplines involves in STEM projects, mathematics indirectly involves as well. Thus, the importance of 'M' in STEM is impossible to ignore.

In this chapter, how "Mathematics" in STEM would be an unavoidable part of STEM and how it should be perceived other than being a subject was emphasized, because mathematics is "the world's single largest educational subject ... applied in a multitude of different ways in a huge variety of extra-mathematical subjects, fields and practice areas" (Niss, 2012, p. 49). Studies revealed that mathematics is a very important subject for students' STEM degree or career choice. Students' mathematics achievement predicted their STEM degree attainment (Tai, Sadler, & Mintzes, 2006; Tyson, Lee, Borman, & Hanson, 2007) and mathematics was one of the important factors explaining STEM career choices (Nicholls, Wolfe, Besterfield-Sacre, & Shuman, 2010). In addition to that STEM environments in early years increased their mathematics achievement compared to others (Oner, 2015). These results showed that mathematics is an essential subject to shape students' future but this does not mean it is not possible to arrange a STEM activity not involving mathematics as subject (i.e. content) when it is needed. What I would like to emphasize is that notwithstanding 'M' in STEM is not obviously included in any activity, it is still would be used as 'mathematical thinking and understanding', 'mathematical problem solving', 'mathematical reasoning', and/or 'mathematical modelling'.

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SECTION 2
21st CENTURY SKILLS AND STEM EDUCATION

Integrated STEM Education: Promoting STEM Literacy and 21st Century Learning

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INTRODUCTION

Rapid changes such as emergence of k-economy, scientific and technological innovation, and advances in information and communication technology (ICT) are visibly experienced in the 21st century. These changes are interconnected and our world is becoming more complex as these changes continues to increase. The complexities of today's world require all people to be equipped with a new set of core knowledge and skills to solve difficult problems. In fact, the global changes has also changed the skills needed for success in the workplace. As widely discussed in the literature, 21st century workplace emphasizes on human capital which are knowledgeable and able to apply knowledge to generate innovations that can contribute to the betterment of society and the improvement of the nation's wealth. In addition to knowledge, innovation in the 21st century requires a new range of skills known as 21st century skills. For instance, effective communication and collaboration problem solving skills are part of the 21st century skills. Increasing levels of complexity require expertise communicate effectively and work collaboratively with people from all over the world to solve problems or create novel products. 21st century skills enable one to navigate successfully in the more complex and competitive life and work environment in the 21st century (Partnership for 21st Century Skills, 2009).

These changes imply that science, technology and innovation are now key for greater social well-being and economic growth. Furthermore, the complexities of today's world require all people to be equipped with science, technology, engineering and mathematics (STEM) knowledge and 21st century skills to solve most problems that are interdisciplinary in nature. Education is the foundation of human capital development, thus school needs to produce students who are STEM-literate and competent in the 21st century skills to become science and technology innovators and remain competitive in the 21st century labour market.

This is highlighted by the CEO Forum on Education and Technology (2001) that the definition of student achievement in the 21st century must be further expanded to include the 21st century skills.

In the Malaysian context, the science and technology innovation has been recognized as essential engine of economic growth to strengthen Malaysia's global competitiveness as well as to propel Malaysia into an innovative nation and achieve the goals of Vision 2020. According to the Science and Technology Human Capital

Roadmap (STHCR) 2020, Malaysia requires 500000 science and technology human capital in 2020 (MOSTI, 2012). Therefore, Malaysia needs to ensure the supply of human capitals who have mastered the knowledge of STEM and 21st century skills to support science and technology innovations.

In line with the current global changes as well as the national vision and mission, Malaysia has instituted the 60:40 (Science/Technical: Arts) Policy to increase the number of science-stream students. The increase in enrolment, however, should be followed by an increase in the students' STEM literacy and 21st century skills. STEM literate students will be capable of identifying, applying, and integrating the STEM concept to understand complex problems and generate innovation to solve the problems (Chew, Noraini, Leong & Mohd Fadzil, 2013). STEM literacy plays an important role in human daily lives in this era since they are many issues related to science and technology. Meanwhile, the 21st century skills are needed to enable students to face challenges of work and life the 21st century (Kamisah, Shaiful Hasnan & Arba'at, 2009).

Henceforth, science education in Malaysia should be shifted to the integration of the acquisition of knowledge and inculcation of 21st century skills to ensure that students are well-equipped with knowledge, skills and values essential to the 21st century everyday life and workplaces productivity.

To contribute towards enhancing the quality of the 21st century human capital, STEM education and 21st century learning have been introduced by the Ministry of Education. Since that, acronym STEM and 21st century classroom have been widely discussed among teachers. However, an understanding of STEM education and 21st century learning vary especially among science and mathematucs teachers. When hearing the term "STEM" and "21st century learning", many conjure images of classrooms equipped with ICTs or using technologies to teach STEM subjects. Others think of teaching students about technology. As a results, some schools started equipping classrooms with computers/smart boards, and began organising apps/robot/software designing courses for students. Moreover, some of teachers do not realize the interconnection of the STEM education and 21st century learning.

Both are seen as two different approaches with different purposes. In short, teachers still pose important questions about how to move STEM education and 21st century education forward.

They struggle to provide students with meaningful STEM experiences that promote 21st century learning. 21st century learning is typically used to describe the types of competencies needed to thrive in today's complex and interconnected global landscape (Bernhardt, 2015).

The inability to understanding meaningfully both STEM education and 21st century learning seems to be the main weakness of many teachers. We believed that this might due to lack of relational understanding – a more meaningful learning. There are generally two different types of understanding: Relational understanding refers to the process of knowing both what to do and why, and instrumental understanding describe the process of knowing rules without reasons (Skemp, 1978). It is a widely-held perception and belief that teachers who understand relationally are more likely to connect new learning with previous learning. However, many Malaysian in-service teachers were taught instrumentally during short-term (one-to five-day) or one-off training courses because given such a limited time. As Orchard and Winch (2015) highlighted, teachers rely on philosophical ideas or theory to make good professional judgments in addition to subject knowledge and technical know-how. For instance, teachers must understand key educational concepts and principles that underpin various practices in order to be able to explain and justify their judgments to pupils, parents and other stakeholders. If they just understand instrumentally, they will be operating as mere technicians. Therefore, in this paper we discuss (1) the theoretical foundations of STEM education, and (2) the guiding principles STEM education that promote STEM literacy and 21st century learning. In addition, we also presents the outline of instructional activities based on the STEM guiding principles.

THERORETICAL FOUNDATIONS OF STEM EDUCATION

STEM education is drawn upon two important theories in learning and education which are constructivism and constructionism. The former focuses on the role of students as builders of meanings and ideas while the latter added that the building of new ideas occur best through constructing real-world artefacts.

Constructivism

Constructivist theory focuses on the role of students as knowledge builders. Among the major theories that contribute to the growth of constructivism include Piaget, Vygotsky and Bruner's theories of learning.

Piaget's theory explains how humans organize information into the cognitive structure and explains how cognitive development occurs. According to Piaget, the new information is organized into existing cognitive structures (schemata) through two cognitive processes, namely assimilation and accommodation. Piaget (1970) asserted that assimilation does not occur without accommodation and vice versa. In other words, assimilation and accommodation are two complementary processes. Piaget also introduces the process of 'increasing equilibration' as key mechanism in cognitive development. This process requires equilibrium between assimilation and accommodation (Piaget, 1970, 1977) to seek for better equilibrium through cycles of equilibrium, disequilibrium and re-equilibrium. Equilibration therefore is a dynamic process. According to Piaget (1977), conflict situations can be created to attain the goal. This means that cognitive development occur when disequilibrium or cognitive conflicts are resolved (Schunk, 2012). The process of equilibration aims to restore equilibrium or resolve conflicts through the processes of assimilation and accommodation which are complementary.

Other aspects in the constructivist theory include learning can be enhanced through social interaction and discovery. Vygotsky (1978) believed that learning is influenced by the social environment and emphasized on the role of social interaction in learning and cognitive development. Collaboration between students with teachers or peers provides scaffolding to students in the Zone of Proximal Development to help them construct knowledge. Meanwhile Bruner (1966) believed that learning and problem solving are the result of the exploration of new knowledge. If students discover knowledge and the relationships on their own, they will gain a deeper understanding (Bruner, 1962).

Briefly, the constructivist theory states that students do not receive knowledge passively, but he/she interpret the knowledge received and then modify the knowledge in a form that acceptable to him/her. In other words, individual student actively constructs new knowledge pursuant to his/her existing knowledge. Construction of new knowledge can be improved through social interaction. Through social interaction, triggering of cognitive conflict and restructuring of ideas will occur when students share their ideas from their own perspective. However, no interaction would be beneficial if new knowledge is presented to students traditionally. Instead, student should be given the opportunity to explore new knowledge.

Constructionism

The theory of constructionism is built on the theory of constructivism which defines learning as knowledge construction in the student's mind. In addition to the constructivist theory, constructionist theory of learning asserts that the construction of new knowledge happen felicitously in a context where students are consciously involved in the production of external and sharable artefacts (Papert 1991). This theory emphasizes the role of design (making, building or programming) (Kafai & Resnick, 1996) and external objects (Egenfeldt-Nielsen, 2006) in facilitating the knowledge construction. In this process, the designers (or students) create artefacts which are significant to themselves based on their interests, learning styles and their experience, and shares their artefacts as well as the artefacts' designing process with others.

The constructionist theory of learning goes beyond the idea of learning-by-doing as indicated by Papert (1999a) that 'I have adapted the word constructionism to refer to everything that has to do with making things and especially to do with learning by making, an idea that includes but goes far beyond the idea of learning by doing'. Indeed, Papertian constructionism challenges the student applying the knowledge being explored to construct more complex ideas or larger theory. In this process, students' knowledge serves as 'instrument of personal power' (Papert 1980). Thus, traditional curriculum model that uses themes and projects as a way to help students learn a particular knowledge or skill (Figure 1) should be flipped (Figure 2) to allow students to use their knowledge and skills to complete a theme-based project. (Stager 2005).

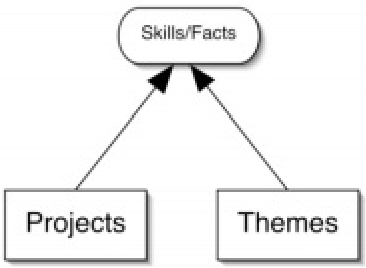

Figure 1. Traditional Curriculum Model

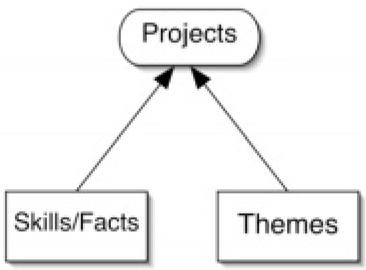

Figure 2. Constructionist Curriculum Model

Source: Stager (2005)

Computers play a role in the constructionist learning theory. Computers can be used as a building material (Papert, 1999a) as well as a 'material to be messed about with' (Papert & Franz, 1988). Learning occurs when students are 'messing about' with the computer. The introduction of computers is also able to change the context of learning (Papert, 1991). Computers can serve as a convivial tool (Falbel, 1991). The willingness of students to learn will increase because they can use the computer in building artefacts (Papert, 1991). Papert (1980) has described that 'The computer is the Proteus of machines. Its essence is its universality, its power to simulate. Because it can take on a thousand forms and can serve a thousand functions, it can appeal to a thousand tastes'. However, he stressed that the main focus is not on the computer but on the minds of students (Papert, 1980). Additionally, constructionist theory also values the diversity of learners and social aspects of learning. According to Kafai dan Resnick (1996), this theory recognizes that learners can build relationship with knowledge through various ways, and community members can act as collaborators, coaches, audiences and co-constructors of knowledge in the constructionist learning environment.

In summary, constructionism proposed that learning can be enhanced if students are involved in collaborative artefact designing projects using digital tools as construction material. Furthermore, students should be encouraged to create prototypes or artefacts from their own ideas. Principles derived from the constructivist and constructionist learning theories are summarized in Figure 3.

1. Knowledge reconstruction: Student constructs new understanding pursuant to his/her existing knowledge.
2. Collaboration: Peer collaboration may trigger cognitive conflict and this may result in reconstruction of ideas.
3. Exploration: Understanding is lifted when students discover new knowledge themselves.
4. Problem solving: New understanding occurs when students discover their own solutions to a problem or a task.
5. Learning through designing: Learning can be enhanced if students are involved in artefact designing projects. Design projects are often interdisciplinary, bringing together knowledge from STEM subjects as well as other disciplines.
6. Construction: Students are challenged to apply what they have learned to construct more complex ideas or larger theory.
7. Technological literacy: Use technology efficiently and effectively to achieve specific goals. Students must be technologically literate to live, learn, and work successfully in today's Digital Age.

Figure 3. Principles of Constructivist and Constructionist Learning

PRINCIPLES OF STEM EDUCATION

Based on constructivist and constructionist learning theories as well as literature analysis, we identified 11 guiding principles that should be incorporated in STEM education:

1. STEM education should contribute towards cultivation of STEM-literate citizenry.

STEM literacy is important both inside and outside STEM fields. Therefore, STEM education should aim to equip students with knowledge, skills and values that are relevant to the 21st century workplace and everyday life. These students will be qualified human capital in STEM-related careers. They will be able to make judicious decisions to invent new technologies to solve various problems in today's world. This is also important for those who never directly pursue STEM-related careers. They will be able to apply the skills that come from studying STEM subjects in solving many problems in their daily life which is dominated by science and technology.

2. STEM education should emphasize development of students' 21st century skills.

The CEO Forum on Education and Technology (2001) and Partnership for 21st Century Skills (2009) have proposed that students' achievement in the 21st century should be expanded further and emphasis should be given simultaneously on improving academic achievements and the 21st century skills. Kamisah and Neelavany (2010) have identified five important clusters of 21st century skills which need to be integrated in the Malaysian science curriculum, namely (1) digital age literacy, (2) inventive thinking, (3) effective communication, (4) high productivity, and (5) spiritual values.

3. STEM education should emphasize multidisciplinary or integrated approach

This may include exploring approaches to tackling global grand challenges of the 21st century such as health, energy efficiency, natural resources, environmental quality and hazard mitigation (Bybee, 2010). STEM disciplines are interrelated (Balaban & Klein, 2006). However, STEM subjects are taught in silo traditionally. Besides, science and mathematics have been emphasized more than engineering and technology in primary and secondary levels. Infusing technology and engineering into science and mathematics learning can cultivate deeper understandings and better development of skills than learning the subjects in isolation (Bryan et al., 2016). Thus, emphasis should be given on providing students with high-quality interdisciplinary STEM learning experiences to solve real-world problems. These problem may include exploring approaches to tackling global grand challenges of our era, such as health, energy efficiency, natural resources, environmental quality and hazard mitigation (Bybee, 2010).

Integrated STEM should mean application and integration of engineering practice with the content and practice of science and mathematics (as well as other disciplines) to design technologies that solve real-world problems through collaboration and communication. In this regard, the engineering practice serve as an integrator – bind together science and mathematics content and practices, as well as meaningfully bring in other disciplines, to produce technologies for a specific purpose (Bryan et al., 2016; Moore et al., 2014).

4. STEM education involved designing shareable technologies, leveraging technologies, and developing technological literacy.

The applications of scientific knowledge and practices to engineering have contributed to the technologies and the systems that support them that serve people today (National Research Council, 2012). ITEA (2000) defines technology as "the innovation, change, or modification of the natural environment in order to satisfy perceived human wants and needs".

Clearly, technology means innovation or products (a single device or a complex systems) that solve problems and extend human capabilities. Design projects are often interdisciplinary, bringing together knowledge from STEM subjects as well as other disciplines. Contemporary technologies such as ICT can be leveraged to communicate, collaborate, solve problems, accomplish tasks and as construction material. However, the focus of integrated STEM is not on the technology alone, but on the fostering innovation and invention as well as promoting technological literacy. Technological literacy is beyond knowledge and application of ICT.

5. STEM education should emphasize collaboration and communication.

Collaboration and communication are two important 21st century skills (Binkley et al., 2012; NCREL & Metiri Group, 2003; Partnership for 21st Century Skills, 2009). Students should be given opportunities to engage in collaborative problem solving or task. Taking part in collaborative task may deepen students' understanding as cognitive conflict may be triggered during activities and hence, new understanding may discover. Moreover, students should be encouraged to use real-world tools (e.g., digital cameras and digital video cameras) to communicate their ideas. Besides, they should be encouraged to communicate information or ideas effectively in multiple format (orally, graphically, textually, etc.). Limiting student expression to pencil and paper makes the demonstration of understanding difficult for many students. Contemporary tools can play a facilitative role in effective collaboration and communication.

6. Integrated STEM education should engage students in argumentation through scientific argumentation and design justification

Just like STEM professionals, students be engaged in learning through inquiry. The process of inquiry required students to engage in argumentation for a claim or decision. Argumentation invites diverse opinions from peers with justifications for their claims. In this process, students make claims based on evidences, listen to input from peers and defend their claims using well-reasoned justifications. Peer's input may guide them towards restructuring existing idea and hence towards deeper level of understanding.

In design activity, engineers collaborate to gather opinions for better solution. Argumentation is used to justify their design decision and explain design process (Baek, Koh, Cho, & Jeong, 2015). Justification of design choices is parallel to the argumentation in science education (Bryan et al., 2016). Bryan et al. (2016) also pointed out that design justification is one way to require the students to apply the science and mathematics to the engineering design. This learning experiences provide opportunities for student to deepen science and mathematics content knowledge as well as engineering thinking or 'habits of mind' (values, attitudes, and thinking skills associated with engineering). Engineering 'habit of mind' align with 21st century skills such as systems thinking, creativity, optimism, collaboration, communication, and ethical considerations (Katehi, Pearson, & Feder, 2009).

7. STEM education should incorporate practices of STEM professionals to develop students' understanding of the nature of science, technology, engineering and mathematics.

Practices are behavior that STEM professionals engage in as they investigate, design and problem solve, as well as build models, theories and systems (Bryan et al., 2016). Practices involve the use of both discipline knowledge and skills specific to each practice (NGSS Lead States, 2013). The practices of STEM professionals includes scientific inquiry, mathematical thinking, and engineering design and engineering thinking. Repeated opportunities engaging in STEM professionals' practices contributes to better understanding of the nature of science, technology, engineering and mathematics. We believed that developing understanding of the nature of science, technology, engineering and mathematics is necessary for STEM literacy for the same reasons that understanding of nature of science and mathematics is a pre-requisite for increasing science literacy and mathematics literacy (Lederman, Lederman, & Antink, 2013; Ojose, 2011)the primary rallying point for science education reform is the perceived level of scientific literacy among a nation's populace. The essential nature of scientific literacy is that which influences students' decisions about personal and societal problems. Beyond this, however, educators work to influence students' ability to view science through a more holistic lens. Examining the philosophy, history, and sociology of science itself has the potential to engender perceptions of science, in the broader context, that can impact the lens through which students view the world. The integration of explicit, reflective instruction about nature of science (NOS).

8. Finally, students are expected to build new solutions or construct more complex ideas or larger theory by leveraging of STEM knowledge and practices as well as 21st century skills and resources. In other words, they become creative problem solvers, innovators and inventors.

IMPLEMENTATION

Based on the constructivist and constructionist learning theories, the IDPCR phases (i.e. Inquiry, Discover, Produce, Communicate and Review) were designed and developed to assist students in carrying out both inquiry and design activities. The IDPCR phases are derived from the BSCS 5E Instructional Model (Bybee et al., 2006) and Creative Design Spiral (Rusk, Resnick, & Cooke, 2009). It is expected that the acronym IDPCR can help students remember the five important domains of 21st century skills, i.e. Inventive thinking, Digital-age literacy, high Productivity, effective Communication and spiritual values (nilai keRohanian). The five domains of 21st century skills have been identified by Kamisah and Neelavany (2010). It is important to point out that the IDPCR phases do not always follow in order. For instance, at any phase, students can communicate information or findings to people from many different backgrounds and specialties to gain input from them. They are also encouraged to communicate in groups and report back with their findings at any phase.

The authors also recognise that the IDPCR phases may be too wordy and abstract for young learners. For young learner, the phases may be reduced to four phases and replace the abstract words with Think, Make, Communicate and Improve (TMCI). The TMCI model is derived from the TMI (Think, Make, Improve) Model (Martinez & Stager, 2013). In our model, 'communicate' is added and made explicit as communication is a fundamental practice of science and engineering (NGSS Lead States, 2013). Communication is also recognised as one of the important 21st century skills.

Table 1.The IDPCR and TMCI Phases, and Related Phases of the BSCS 5E Instructional Model, Creative Design Spiral, and the Science and Engineering Practices.

TMCI	IDPCR	BSCS 5E Instructional Model	Creative Design Spiral
Think	Inquiry	Engage	Imagine
	Discover	Explore	Experiment
Make	Produce	Elaborate	Create
Communicate	Communicate	Explain	Share
Improve	Review	Evaluate	Reflect

In the following section, the authors present the outline of instructional activities based on the STEM guiding principles. The instructional activities were designed to engage students in practices of STEM professionals.

Table 2. Outline of Instructional Activities

IDPCR Phase	Purpose	Inquiry Activity	Design Activity
Inquiry *Predict, ask, hypothesize, identify problem, brainstorm*	1. Arouse students' interest 2. Access students' prior knowledge 3. Elicit students' misconceptions 4. Clarify and exchange current conceptions	1. Teacher shows discrepant events. 2. Students ask questions about the phenomena they observe. 3. Students explain the phenomena at the sub-microscopic and symbolic levels. 4. Students develop and/or use models to describe and/or predict phenomena. 5. Students discuss in groups and compare their ideas with their peers. 6. Students do background research by obtaining and evaluating information from various sources.	1. Students define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution. 2. Students do background research by obtaining and evaluating information from various sources. 3. Students brainstorm ideas to develop as many solutions as possible. 4. Students convey possible solutions through visual or physical representations. 5. Students develop models to represent events or possible solutions.
Discover *Investigate, experiment, explore*	1. Expose to conflicting situations 2. Modify current conceptions and develop new conceptions 3. Provide opportunities for students to demonstrate their conceptual understanding, and skills	1. Students formulate hypothesis and identify variables. 2. Students plan and perform investigation in groups. 3. Students analyse and interpret data, and draw conclusion. 4. Students use mathematics and computational thinking. 5. Students use laboratory tools connected to computers for observing, measuring, recording, and processing data. 6. Students engage in discussions and information seeking using ICT or talking to experts. 7. Students practise the skills needed in scientific investigations. 8. Students communicates in groups and report back with their findings.	1. Students selecting a promising solution. 2. Students plan and create prototype. 3. Students test the prototype and redesign prototype as necessary. 4. Students analyse and interpret data. 5. Students use mathematics and computational thinking. 6. Students use laboratory tools connected to computers for observing, measuring, recording, and processing data. 9. Students engage in discussions and information seeking using ICT or talking to experts. 7. Students practise the skills needed in engineering design activities. 8. Students communicates in groups and report back with their findings. 9.

Produce *Create, construct, invent, build, design, tinker, elaborate*	1. Challenge and deepen students' conceptual understanding and skills 2. Provide additional time and experiences that contribute to the generation of new understanding	1. Students generate explanation for the causes of phenomena supported by evidences consistent with STEM knowledge. 2. Students develop and/or use models to describe phenomena. 3. Students apply their new ideas by conducting additional activities that are more complex and involve HOTS. 4. Students apply new idea and develop technologies to solve problems based on IDPCR or TMCI phases.	1. Students create final prototype based on data from testing. 2. Teacher reminds students of the basic steps of the engineering design process. This is a cyclical process that requires innovators to test and redesign creations as often as it takes so that they end up with reliable finished products. 3. Students generate explanation for the design solution supported by evidences consistent with STEM knowledge.
Communicate *Explain, share, discuss with peers, ask an expert, defend*	1. Provide opportunities for students to share their new understanding and skills 2. Provide opportunities for students to exchange their new understanding	1. Students communicate their ideas, process and new findings through oral presentation. 2. Students summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. 3. Students engage in argument from evidence. 4. Students use real-world tools and multiple formats to communicate information or ideas. 5. Students also listen to input from peers and defend their ideas. Peer's input may guide them towards deeper level of understanding. 6. Students compare their ideas with the teacher's explanations.	1. Students communicate their design, process and solution through oral presentation. 2. Students summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. 3. Students engage in design justification or argument from evidence. 4. Students use real-world tools and multiple formats to communicate information or ideas. 5. Students also listen to input from peers and defend their ideas. Peer's input may guide them towards deeper level of understanding. 6. Students compare their designs.
Review *Check, evaluate, reflect, improve, repair*	1. Students assess their understanding, skills and competencies 2. Students think creatively for the purpose of improvement 3. Teachers evaluate student progress	1. Students reflect upon the extent to which their understanding, abilities and competencies have changed. 2. Students reflect on the practices of science and engineering. 3. Students improve their ideas or skills based on reflection or input from peers. 4. Teacher conducts tests to determine the level of	1. Students describe the key strengths and weaknesses of their designs. 2. Students improve their prototype in groups that incorporates the best aspects of all the designs, as well as improvements suggested through testing. 3. Students reflect upon the extent to which their understanding, abilities and competencies have changed.

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STEM SKILLS in the 21ST CENTURY EDUCATION

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Introduction

STEM education, as one of the most striking educational movements in recent years (Kuenzi, 2008; Reiss & Holmen, 2007; Sanders, 2009), is an interdisciplinary field of study linking science, technology, engineering, and mathematics (National Governors' Association, 2007).

Mobley (2015) describes STEM education as "an educational approach in which interdisciplinary applications are made to solve problems in real life and links to different disciplines are created". STEM education emerges as an interdisciplinary concept involving teaching science, technology, engineering, and mathematics under one roof. STEM education provides a positive contribution to students' basic skills (problem solving, critical thinking, etc.) by creating interdisciplinary study opportunities (Australian Education Council, 2015). In addition to supporting development of 21st century skills such as STEM literacy, problem solving, critical thinking and creativity (Australian Education Council, 2015; Bybee, 2010; Innovation America Task Force, 2007; Morrison, 2006), STEM education emphasizes three fundamental elements (problem solving, innovation, and design) that have a significant place on every countries' agenda (Hernandez et al., 2014).

STEM education is a learning and teaching approach that integrates science, technology, engineering and mathematics knowledge and skills (Maryland, 2012). STEM education is aimed at the development of students' research-questioning, logical reasoning, and working behaviors in a collaboration. In this respect, the aim of STEM education is to train qualified individuals to meet the 21st century workforce needs (Moore, 2009). With the STEM education, it is aimed that students will work to find solutions to complex problems and global problems and to improve their real life situations (Breiner, Harkness, Johnson, & Koehler, 2012; Sanders, 2009; Wang, Moore, Roehrig, & Park, 2011).

21st Century Skills

The 21st century skills have great importance for a successful school and business life (Washer, 2007). Because transferring the courses in the education programs to the students is necessary for academic success but it is not enough to make a difference in the 21st century we are in (Jerald, 2009). In this context, education is being regulated in order to meet the needs of workforce in industry and economy-oriented occupational fields (Bingimlas, 2009; Gooderham, 2014; Hudson, 2001). It is aimed to educate the individuals who can respond to the needs of the 21st century with these regulations made in the field of education. Thus, interdisciplinary education programs are offered as an alternative to traditional education for the development of 21st century skills (Davies & Ryan, 2011).

One of the aims of STEM education is to develop individuals' 21st century skills (Bybee, 2010). These skills are expressed by NAS (2014) as "providing a meaningful and deep understanding and transfer of knowledge among disciplines". In the 21st century education, the importance of realizing interdisciplinary, personalized, inclusive, flexible, collaborative, student-centered, engaging and exciting teaching environment has been expressed by Cookson (2009) as follows. In providing quality education, global competitive environment, classes and schools must be structured towards 21st century skills and knowledge and skills must be integrated and implemented by educators.

Our world is rapidly evolving in terms of technology and knowledge, and students need to develop the skills they need to be in the changing world (Darling-Hammond, 2010; Friedman 2005; Wagner, 2008). Education is increasing its importance every day in terms of adaptation to changing world and economic competitiveness. Moore (2009) states that in the 21st century, with the changing educational insight, the targeted skills to be acquired by the students must change as well. While students are aiming to compete in a global economy, education and skills at the K-12 level need to be aligned to this goal (Darling-Hammond 2010; Friedman, 2005; Wagner, 2008). For this purpose, curriculum, content, and evaluations should be adapted to student skills and needs and focused on 21st century skills (Friedman, 2005).

Jukes & Macdonald (2007) suggest that 21st century skills must be understood by teachers and taught to students with an effective teaching style. In an effective 21st century education, it is aimed to acquire basic skills such as reading, speaking, and writing as well as social, academic, and engineering skills (Jukes & Macdonald, 2007).

In this context, Jerald (2009) describes the skills that individuals should have in the 21st century society; basic knowledge and skills (academic knowledge and skills), literacy skills (ability to apply academic knowledge and skills in real life) and 21st century skills (ability to use literacy and other skills at any time to succeed in different areas of life).

Today, many sectors expect individuals to have the skills appropriate for the needs of the age, such as problem solving, creative thinking, high communication skills, being open to collaboration, having responsibility, etc. (Eryılmaz & Uluyol, 2015). 21st century skills helps students to easily adapt to the new situation while they are being taught the new knowledge (Dede, 2010). Along with these skills, students are able to adapt to the ever-changing and evolving global community (Pearson, 2014).

When the literature is examined, there is no consensus on what the 21st century skills are (Sahin, Ayar, & Adıgüzel, 2014). However, various institutions and researchers are conducting extensive researches to explain these skills. One of the most important work undertaken in this regard was the Partnership for 21st Century Skills. Partnership for 21st Century Skills (2011) explain the 21st century skills as follows:

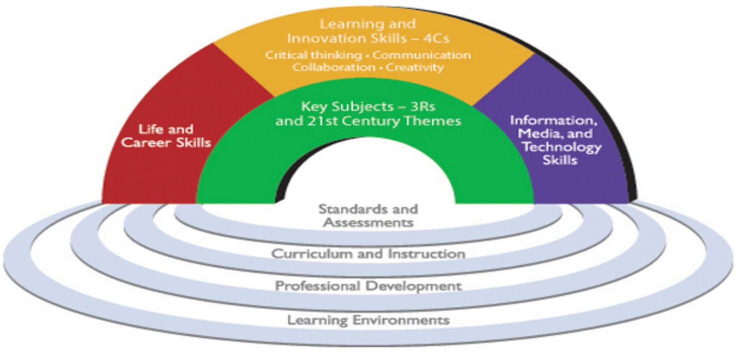

Figure 1. Partnership for 21st Century Skills

Fundamental Issues & 21st Century Themes: Basic topics include fields such as reading, science, mathematics, language, history, and economics. It is aimed to transfer knowledge to solve social problems such as global awareness, finance, economy, environment and health, which are more complex in the academic sense, by associating these basic fields with each other.

Learning and Innovation Skills: With the school and non-school experiences, it is aimed to ensure that students are in an effective learning process. In addition to giving the knowledge to students, awareness should be raised in self-development and innovation in the changing world.

- Critical Thinking and Problem Solving Ability: Critical thinking involves effectively analyzing and evaluating assertions, evidence, and beliefs.

In the 21st century, problem solving skills are effective in helping individuals solve unconventional situations with effective methods.

- Communication: The individual must express his/her ideas in various contexts by using verbal or written communication tools effectively. Effective communication skills gain importance in this direction.

- Collaboration: Individuals need to be able to work in a respectful manner with different teams in the educational environment and business life. With the collaborative education practices, students should be immersed in collaboration.
- Creativity and Innovation: The ability to produce a broad idea to create new and useful ideas.

Knowledge, Media and Technology Skills: The skills that individuals should have in the 21st century are (i) access to a wealth of information, (ii) adaptation to rapid changes in technologic tools, and (iii) contributing by working individually and in collaboration.

- Knowledge Literacy: Accessing and evaluating knowledge critically and competently, managing the flow of knowledge from various sources.
- Media Literacy: Understand how and why media messages are created; understanding and using the most appropriate media creation tools and features to bring media products to the market.
- ICT (Information and Communication Technologies) literacy: Using technological tools as a means of researching, organizing, evaluating and transmitting information.
- Life and Career Skills: In today’s global competition, students need to be careful to improve their life and career skills in highly competitive life and work environments.
- Social and Intercultural Skills: Students need to have content knowledge, social and emotional competencies in order to be able to take place in real life and in future working environment.

K-(4-8) STEM Skills in Turkey

In Turkey’s Middle School Mathematics Course (5, 6, 7 and 8. Classes) Curriculum (2013), the targeted basic skills were determined as problem solving, mathematical process skills (communication, reasoning, and association), sensual skills, psychomotor skills, and information and communication technologies. In the updated Mathematics Curriculum (MoNE, 2018a), mathematical skills have been included as mathematical competencies. Mathematical competencies include the ability and desire to use mathematical modes of mathematical thinking (logical and spatial thinking) and presentation (formulas, models, fictions, graphics and tables) at different levels.

In the Science Curriculum (MoNE, 2018b), specific skills in the field were categorized as scientific process skills, life skills, and engineering and design skills. Scientific process skills include observing, classifying, recording data, constructing hypotheses, using and modeling data, changing and controlling variables, experimenting. Life skills include analytical thinking, decision-making, creativity, entrepreneurship, communication and teamwork skills related to access to and use of scientific knowledge. Engineering and design skills in the curriculum include strategies on how students can create products and how they can add value to these products using the knowledge and skills they acquire by integrating science, mathematics, technology and engineering and bringing students to the level of being able to make innovations with an interdisciplinary approach to the problems.

Objectives of the 7th and 8th grade Technology and Design Teaching Program (MoNE, 2018c) are to raise individuals who are able to observe and interpret the objects, events and phenomena around in an analytical way, to identify the problems and develop creative and original alternative suggestions, and make evaluations of these suggestions and make decisions for the best suggestion. At the same time, it is aimed to raise individuals who observe, examine, sensitive to environment, feel responsible about the problems that affect human life, propose innovative and original solutions to these problems by using analytical thinking system, have self-confidence, and have skills to work in collaboration.

In this study, it was aimed to examine the skills that are aimed to be taught in science, mathematics, technology and design courses for the 4-8 classes prepared by the Ministry of National Education and the 21st century skills defined by Partnership for 21st Century Skills (2011) and to define the STEM skills within the scope of STEM education. Identification of STEM skills is aimed at identifying the specific skills of STEM training.

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STEM SKILLS

When the literature is examined, it is seen that some skills are accepted as STEM skills and there is a common understanding. These skills are emerging in the form of Engineering Based Problem Solving Skill, Association Skill, Engineering Based Design Skills, Innovation, Digital Competence, Creativity, and Communication and Collaboration.

Engineering Based Problem Solving Skill

In STEM education, problem-solving skills are effective in engineering processes that involve planning, designing, constructing, and evaluating for a specific problem (Bagiati

& Evangelou, 2016; English & King, 2015). Problem solving processes in students' engineering work are described as follows (English, King, & Smeed, 2017; Lucas, Claxton, & Hanson, 2014):

- Identify the problem situation,
- Produce possible solutions for the problem and to evaluate the solutions to meet the problem,
- Test the possible solutions and solve the problem.

During the STEM activities, the students are "learning while doing design" by testing and checking their products during the engineering process brought to the problem solving stage (Crismond & Adams, 2012). STEM education provides a rich content for engineering-based innovative and creative problem solving (Bagiati & Evangelou, 2016; English, 2016). English, King, and Smeed (2017) describe the following steps for problem solving in STEM education:

1. Determining and Identifying the Problem Situation: In determining the problem situation, which is the most basic stage of the design process, the problem situation is extensively addressed and the limitations and targets are determined (Atman et al., 2014; Watkins et al., 2014). Since real-life problems in STEM activities are complex, determining these problems and defining their limitations is effective in constructing problem solutions (Jonassen, Strobel, & Lee, 2006). The problem situation is an important step because it affects the process of designing and delivering products (Atman et al., 2008). Determining the problem situation is an essential step in the design model and specifies the choice of material to be used for the product that will help in solving the problem (English, King, & Smeed, 2017).

2. Product Development for Problem Solving: In order to solve the problem in STEM education, the product is introduced to the market. For this purpose, the stages of planning, preparing, designing, evaluating, redesigning and producing products are included (Portsmore et al., 2012). At this stage, students convey their thoughts about their products in different representations via verbal, written, visual or 3D modeling (English & King, 2015). Drawing skills of students in designing by drawing, computer and modeling program skills of students in 3D models, and communication skills of students in expressing thoughts are effective (Postmore et al., 2012).

3. Product Evaluation and Configuration: The product evaluation phase is important to develop in-depth understanding of the problem (Mehalik, Doppelt, & Schun, 2008). Kendall (2018) states that product evaluation encourages students

in identifying, correcting, and improving the inadequacies of their products. Students try to identify the causes and shortcomings of the their products and improve them. Students have the ability to design and produce product based on academic knowledge of STEM disciplines in problem solving (Watkins et al., 2014; Katehi, Pearson, & Feder, 2009). In this respect, the students' failure to deliver the product may be related to academic knowledge and skills.

Skills for Establishing Relevance

With STEM education, it is aimed to teach students to relate science, technology, mathematics, and engineering within themselves, with other disciplines, and real life; therefore, learning will be meaningful. Through within disciplines, interdisciplinary, and real life relations, instructional content is related to the way it is practiced and makes it meaningful. The types of relations identified within the scope of the study are presented below.

Relating Existing Knowledge with New Knowledge: Piaget (1977) expresses learning as a structure that is improved and organized form of existing scheme by the experiences acquired through the senses. Pound (1977) states that the beginning of the meaningful teaching is the preliminary knowledge of the students and that the relation with the newly learned knowledge should be established. In this direction, it is necessary for students to make connections between the existing knowledge of students in the disciplines of science, mathematics, technology and engineering, and the knowledge they newly learn about these disciplines.

Relating STEM Disciplines within Themselves: In order to establish links between STEM disciplines, prior knowledge and needs of students for each discipline need to be identified and addressed. It is also aimed at establishing links between disciplines as well as the necessity of establishing links between prior knowledge and new experiences in the realization of the teaching.

By relating STEM disciplines within themselves, students are able to understand the relationships and benefits among these disciplines rather than thinking that disciplines include a range of disjointed and isolated concepts and skills. In this way, students can be aware of the relationships for each discipline.

Students can relate at any stage of education. While students in kindergarten relate the new knowledge with the experiences they have outside the school, the students at each level of the elementary education relate the new knowledge with the ones learned in previous stage and the daily life. In the upper levels of education, this relation can be improved as abstraction and generalization. Through this relation, students can realize that each STEM discipline is connected and related.

Relation Between STEM Disciplines: In STEM education and its applications, it is also aimed to enable students to relate disciplines with each other as well as students' relations for each of science, technology, engineering, and mathematics. In this way, how the disciplines are located in each other, its importance, and its effect are recognized.

Relating STEM Disciplines with Different Disciplines: STEM disciplines can be related with many fields such as art, language, history, and geography. Instead of introducing STEM fields as related with each other and isolated from other disciplines, we can claim that STEM fields are also effective in different disciplines. This provides students with an awareness of the importance of STEM education. The STEM skill for establishing relevance scheme defined within the scope of STEM skills is given in Figure 2.

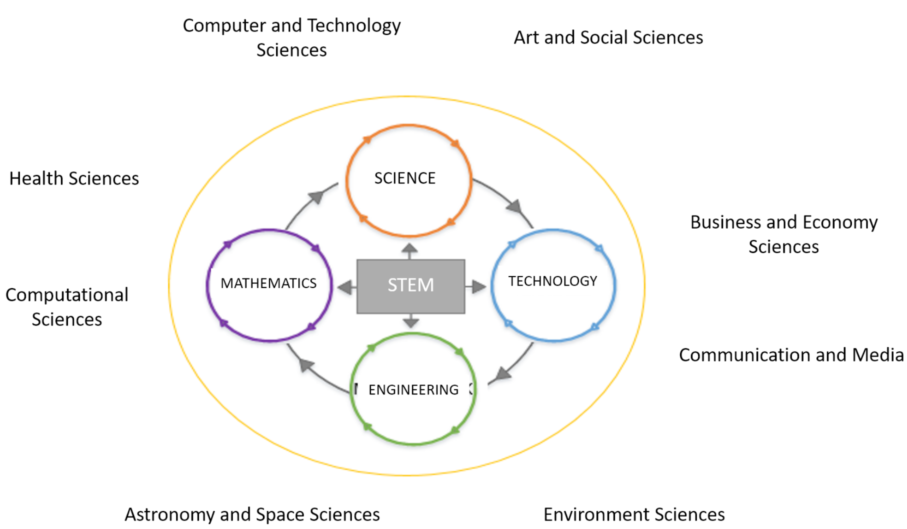

Figure 2. STEM Education Skill for Establishing Relevance

Engineering Based Design Skills

The National Research Council (NRC, 2012) emphasizes, in the development of scientific content knowledge, the importance of integration education that includes engineering design practices. Engineering is defined as "systematic design in producing successful solutions to real life problems" (NRC, 2012). By integrating engineering into education, students have the opportunity to be effective in solving complex problems and decision-making in the future (Mangiante & Moore, 2015). The importance of engineering education arises in having sufficient engineering and scientific knowledge to make solutions to complex social problems such as environment, energy, economy and health, and to participate in discussions and to make decisions in these difficult issues.

It is emphasized by NGSS Lead States (2013) that students should participate in engineering applications according to their interest and experience while developing their engineering skills and equality of opportunity should be provided for them. With

STEM education, it is also stated that the integrated use of scientific knowledge and engineering knowledge in the solution of real life problems is effective in the acquisition of engineering skills of students (Ke, 2014; Thibaut, 2018).

During the STEM education, engineering based design skills are defined by taking into account the skills that students should have in defining the problem, producing solutions for the problem and evaluating the solutions.

Designing: Design becomes salient when students put forward the situation for realistic life problems and develop solution proposals for these problems. Students are expected to design models for the characteristics of the defined problem and to express and reflect these designs in different ways (drawing, modeling, presentation etc.).

Explanation of Design Process: Students are expected to explain the effectiveness of their designs. They need to express themselves what they pay attention to during the design process, whether the design they create is effective in problem solving, and about the developmental stages, and at the same time evaluate whether the design they construct serves to solve the problem.

Selection of Appropriate Materials: Selection of appropriate materials is necessary for putting the designs created by the students for problem solving as products. For this, it is important to test and evaluate different material alternatives. The selection of suitable materials is important for the development of a durable, flexible, and usable product.

Realistic Product Creation: It is important that the designs that are created to solve the problem are realistic and useful. The fact that the products that students bring to the market are not realistic can cause the problem resolution to be limited. It is important to design well and create an effective model in creating realistic products.

Testing Product Quality and Performance: The crated product must be tested in order to check the durability and operation of it.

The usefulness of the product, its functioning and its effectiveness in problem solving should be tested.

Product Evaluation and Improvement: Product effectiveness, its functioning, its fit to desired characteristics, and durability should be evaluated by the student and the product characteristics should be defined. If the product has incomplete or improvable characteristics, they should be detected and revised to be used in the best possible way.

Design and Product Comparison: It is a comparison of the design the student has made for the problem he/she defined with the product characteristics that he/she presents. At this stage, it is expected that students will question the differences and reasons between what is targeted and what is being done. With the "why" and "how" questions, It is aimed to evaluate the stages of creating the product.

Innovation Skills

Today, as innovation and development in the field of economy, technology and industry are rapidly gaining importance, countries need qualified people with appropriate education to increase and support their knowledge base in this race. At all levels of K-12 education, it is necessary to acquire the knowledge and skills necessary for innovation (OECD, 2011).

Innovation skills provide vocational competence and qualification in the direction of objectives. It is seen that there are common skills defined when the literature on innovation skills is examined (Ananiadou & Claro, 2009; Kergroach, 2008; OECD, 2010, OECD, 2001; Stasz, 2001).

Basic Skills and Digital Age Literacy: Basic skills include the skills for reading, writing and arithmetic operations. Digital age literacy, which provides information access and information interpretation of individuals, provides technology flow that enables the use of digital technology, communication tools and networks. With the development of Internet and information and communication technologies (ICT), OECD (2008) stated that digital age literacy has become as important as the basic skills for the future professions.

Academic Skills: These are related to subject areas such as mathematics, science, history and geography. Academic skills are generally acquired through education and transferred to real life and practice.

Technical Skills: These skills are the skills necessary for professional life and include academic knowledge and skills. It is an increasingly important skill for competence in product, service, and development processes in response to complex problems in industrial development and country policies.

General Skills: The skills involved in this category are problem solving, critical and creative thinking, learning, and managing complex situations.

Social Skills: Social skills include motivation, communication, collaboration and responsibility skills that enable individuals to interact within a group or with other groups. The ability to read and manage one's own and others' behavior during social interaction, as well as the development of comprehension, openness and awareness skills for intercultural communication are important. Leadership: This skill includes team building and managing, guidance and coordination skills.

These skills described are confronted as features that individuals who are effective in the innovation process must possess. Green, Jones, and Miles (2007) define innovation processes and effective skills as follows. These are:

1. Choice of ideas and resources: In this first stage, the identification of ideas, the collection of resources, and the selection of appropriate resources are included. Review of sources, interpretation of new information obtained, evaluation of their validity, and discussion of ideas are carried out. Basic, academic, general, and technical skills are important at this stage.
2. Development of innovation ideas: In this stage of development, individuals or different groups come together to share ideas, make decisions and work effectively. Social and leadership skills gain importance at this stage.
3. Testing and commercialization: At this stage, evaluation of trade, benefits and risks takes place. Customer needs and preferences should be determined in the preference of the product. At this stage, engineering and marketing skills are required for product development and commercialization. Risk management, following and identifying innovations are needed.
4. Implementation and expansion: At this stage, project management, technology transfer, and coordination of supply chains are included.

Digital Competence

Digital competence includes the effective utilization and use of information and communication technologies (MoNE, 2018c). Banks and Barlex (2014) state that digital competence should include the following elements:

- Understanding the use of information and communication technologies (books, Internet, television, telephone etc.) and their reflection on society (culture, information access, communication and interaction, meaning making).
- Making use of technological tools to exchange information and create knowledge via technology as well as face-to-face meetings.
- Effectively utilize and critically evaluate communication technologies to acquire information.
- Taking advantage of networks and multimedia to share information accessed with a digitally literate audience.

There is a need for teaching that integrates technology with engineering applications and includes enriched and high quality teaching materials (PCAST, 2010). With STEM education, students are able to use algorithmic thinking, calculation techniques, modeling, and abstraction to solve real life problems by taking advantage of technology (NAE, 2009). Within the scope of STEM education, it is aimed not only to use technology in education environment, but also to develop technology usage skills of students (Sade & Coll, 2003). In STEM education, it is aimed students to benefit from the information and communication technologies in using, accessing and sharing the information with others while making creative designs, through these activities it is aimed students to develop their digital competencies (Thibaut, 2018).

Communication and Collaboration

In STEM education where engineering design-focused work is involved, students interact in a communicative and collaborative way (Crismond & Adams, 2012). Communication and collaboration have emerged as a necessity in K-12 level engineering programs (ABET, 2012). In STEM education, students work together as engineers in a team to present their design projects (Borrego, Karlin, McNair, & Beddoes, 2013).

In STEM education, students use different communication channels such as written, verbal, visual, and technological. Fluent speech, proper reading and writing, and using digital technologies are effective in expressing students' thoughts.

Trilling and Fadel (2009) expressed the importance of effective communication as follows.

Effective communicative individuals;

- Express their thoughts and ideas in verbal, written and different ways of communication in different contexts.
- Are effective listeners in developing meaning towards knowledge, value, and attitude.
- Can communicate with different purposes (informing, motivating, convince etc.).
- Can benefit from information and communication technologies (computers, cameras, printers, smartphones etc.) effectively.

In STEM education, students are provided to work in interaction with different teams and heterogeneous groups. Communication, motivation and entrepreneurship skills are at the forefront in the social interaction of the students. Leadership skills are effective in the formation of teams and coordination within the group when students work in collaboration. The importance of collaboration is described by Trilling and Fadel (2009) as follows:

- Demonstrate the ability to work effectively with respect to different teams.

- Ability to work towards a common goal and to be flexible and adaptable in making joint decisions.
- Contribution of each individual in group work and shared responsibility.

Socially, communication and collaboration in physical or virtual environment with others are provided for the development of communication and collaboration skills of students (Trilling & Fadel, 2009). According to the OECD (2011), social skills in communication and collaboration are important elements in harmonizing and supporting each other in the globalized world. The ability to work in multicultural groups affects the work of the individual in terms of professional and career.

Life and Career Skills

Life and career skills are effective in making individuals fit into work life and real life. In science education program of Turkey in 2017, these skills were described as analytical thinking, decision-making, creative thinking, entrepreneurship, communication, and teamwork (MoNE, 2017).

These skills are also important competencies in STEM education. With STEM education, it is aimed to develop skills for career and business life following the individuals' school life (Hall, 2018). Students need to be knowledgeable about the basic scientific disciplines that will be effective in their future business life. STEM education is effective in providing students with the knowledge and skills necessary for career and personal development (P21, 2015). The Framework for 21st Century Learning (P21, 2011) describes the elements of life and career skills as follows:

Flexibility and Adaptability: The 21st century business environment, working conditions and needs are changing rapidly, so it is necessary to educate individuals who are not only equipped in the sense of knowledge but also adapt to changing conditions, new ideas, and tasks (Kivunja, 2015).

Entrepreneurship and Self-direction Skills: Today, economy and digital technologies are rapidly evolving and changing. This requires employees to be entrepreneurial and self-directed to learn new ideas, concepts, and practices to increase their productivity (Trilling & Fadel, 2009).

Social and Intercultural Skills: In order to be successful in the 21st century business life, the social and intercultural skills of people need to be effective. These skills enable people to work together effectively or to work effectively with the people they communicate with and with different teams (Kivunja, 2015). In the globalizing world, different countries, different societies, and organizations are involved in shared works through collaboration and communication with each other. In this respect, the ability of individuals to work intercultural is important in terms of ensuring communication and collaboration. Productivity and Responsibility: This skill, which is described by Trilling and Fadel (2009) as "producing results", includes the productivity, usefulness and high-quality service elements interacting with each other. Productivity in providing a quality service includes providing economic support by using resources in the best possible way. The utility of the resulting service and product is indicative of productivity in the work.

Leadership: Leadership skills of individuals are effective in coordinating and sharing tasks among individuals in collaborative group and teamwork (OECD, 2010).

Creativity

Creativity is defined as the ability to think differently and produce ideas as a results of different thinking (Guilford, 1959). Amabile (1982) refers to creativity as producing new and appropriate ideas and behaviors. Csikszentmihalyi (1996) defines creativity as new and valuable ideas or behaviors that are revealed as an interaction of the individual in their thought and socio-cultural context.

Sternberg and Kaufman (2010) state that creativity is generally defined as an understanding of authenticity outside of standards, but creativity is a skill far beyond this definition. Some say creativity is very high level and legendary, while others view it as a skill that emerges in everyday life (Craft, 2002). Creativity is associated with artistic activities and practices, as well as scientific understanding and innovations (Runco & Pagnani, 2011). Creativity is generally defined as "the ability to produce a new, qualified and appropriate product (idea, thought, behavior etc.)" (Sternberg, Kaufman, & Pretz, 2002).

A framework of creativity that can be incorporated into the teaching process was created by Rhodes (1961) and a 4-Ps model was defined in this framework (Smith & Smith, 2010). Rhodes (1961) has described four intertwined elements interacting with each other on a basis of creativity; person, process, product, and press. The 4-Ps in this definition are explained below.

Person: This element includes characteristics specific to person such as personality, intelligence, temperament, attitude, and behavior (Zenasni, Besancon, & Lubart, 2008).

Process: This is the most mysterious component of creativity (Guo & Woulfin, 2016). The process includes the creative work in students' practices and activities. In this direction, various theories and models have been presented in evaluating the creativity of the researchers and practitioners. For example, establishing relationships between concepts (Mednick, 1962) or the Gene-Plore model that involves generating ideas for exploring different contexts (Finke, Ward, & Smith, 1992).

Product: The third line of creativity is the product made at the end of the creative process. Not only the constructions, pictures or inventions that are built as products, but also ideas and thoughts that are suitable for embodiment are also included as creative products (Rhodes, 1961). For example, a new building model that the individual has designed may be a product because of its feasibility, even if it has not been built yet.

Press: Press is the last element of creativity. The press is expressed as the environment in which the individual interacts (Amabile et al., 2004). Guo and Woulfin (2016) described elements that include creative environment in schools as teaching style, peer relations, collaboration, competition, and information and communication technologies.

At the STEM activities, it is aimed students to make a product after an engineering based work process. With STEM education, students are offered the opportunity to make products in a creative environment. In this direction, the students have the chance to design, make products, and evaluate these products within the scope of the 4-Ps creativity model.

Conclusion

Despite the fact that the STEM concept is used frequently today, it is seen that the skills to be developed in students with STEM education is not mentioned too much. STEM education is generally seen as a general concept expressing the integration of science, mathematics, technology, and engineering disciplines. It has become important to develop skills that will emerge through the integration of these disciplines with STEM education. In this section, STEM skills by examining the literature is outlined in the form of engineering based problem solving, establishing interdisciplinary relevance, engineering based design skills, scientific process skills, life and career skills, creativity, innovation, and digital competence. In addition to integrating science, technology, engineering, and mathematics subjects in STEM education, the development of STEM skills is also of great importance.

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SECTION 3
DIFFERENT PERSPECTIVES ON STEM EDUCATION

Catalyzing Fundamental STEM Paradigms in the Accountability Millennium

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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 $SD_{pooled} = \surd(X_1-\bar{X}_1+X_2-\bar{X}_2)/(N_1+N_2)$. 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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Closing the STEM Achievement Gap from a Unified Global Perspective

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Introduction

Closing the achievement gap has become a focal point of education reform efforts and many nations have made it their mission to close the gap. Efforts to combat the gap have been numerous but fragmented, and have ranged from affirmative action and multicultural education to finance equalization, improving teacher quality and school testing and accountability programs to create equal educational opportunities.

The Achievement Gap is defined in many ways. In the U.S it is defined as the observed disparity on a number of educational measures in academic performance between different groups of students, especially groups defined by race/ethnicity, gender, and socioeconomic status. Other countries use some of these terms, such as socio-economic status, ethnicity and gender, but they also include geography, race, class and caste in defining the achievement gap in their country. The achievement gap can be observed on a variety of measures, including standardized test scores, grade point average, dropout rates, and college-enrollment and –college-completion rates.

In the U.S., *achievement gap* is typically used to describe the disparity in test scores between minorities, usually between Blacks and Hispanics and their White (and Asian) peers, and between high-poverty students and their more wealthy counterparts. At each grade level, racial disparities on an array of achievement variables demonstrate a wide gap in performance, especially in mathematics and science, particularly among disadvantaged minorities from urban and rural communities. These disparities start as early as kindergarten, persisting across grades, and in most cases widen over time. Although standardized tests are the standard measurements for the achievement gap used in the United States a variety of measures, including standardized test scores, grade point average, dropout rates, and college-enrollment and-completion rates are used in other countries.

The United States uses the National Assessment of Education Progress (NAEP, the Nation's Report Card) to assess the performance of students in grades 4, 8, and 12. It ranks student performance according to three achievement levels: (1) **basic**—student has partial mastery of prerequisite knowledge and skills that are fundamental for proficient at each grade; (2) **proficient** –student demonstrates solid academic performance for each grade level assessed; (3) **advanced**—student demonstrates superior performance. Many countries use the evaluation results of the Program for International Student Assessment (PISA). Most countries participating in PISA are members of the Organisation for Economic Co-operation and Development (OECD), although the number of participating non-OECD nations and regions is increasing. Most OECD countries are economically advanced nations (NSB, 2012).

Data from NAEP indicate that Blacks and Hispanics made strides in closing the gap until the mid-1980s, at which point those gains began to level off. For example, in the 2009 NAEP results, the gap between Black and Hispanic fourth-grade students and their White counterparts in mathematics was more than 20 points.In eighth-grade mathematics, the gap was more than 26 points.

Various gaps exist between groups all over the globe. A recent book by Clark (2014) provides a rich tapestry on the achievement gap in science, technology, engineering, and mathematics (STEM) in selected countries around the world (Australia, Brazil, Canada, China, UK, Korea, Mexico, Singapore, South Africa, Turkey, and the U.S), These countries were selected because of their uniqueness and the work they are doing in their educational school system to change a practice that will help all students, especially poor, low-income students and students of color to succeed. The school systems are also diverse. Each country offers us something to learn. Many countries, especially Asian countries, have developed and implemented unique models to meet the demands of today's learners. For example, in Singapore, the education system is flexible and caters to every child's abilities, interests, and aptitudes so as to help each develop to his fullest potential. It focuses on the development of human resources to meet Singapore's need for an educated and skilled workforce. It also facilitates the inclusion of social moral values to serve as cultural ballast in the face of rapid progress and change.

The countries in the study have all implemented unique system models to meet the demands of their students. Some of the models include structural, administrative, curriculum changes that government/policy makers have suggested or enforced. Some Countries have built strong education systems creating productive teaching and learning systems by expanding access while investing purposefully in ambitious. There is no single way in closing the achievement gap.

The Achievement Gap in the United States

The achievement gap in the United States refers to the disparity in academic performance, as shown by standardized test scores, between groups of students, mainly minorities: Blacks (African Americans), Hispanics (Latinos), Native Americans (American Indians), and their White (and Asian) peers. The gap is usually defined based on students' performance in elementary and secondary school in the subject areas of mathematics, science and reading. At each grade level, racial disparities on an array of achievement variables demonstrate a wide gap in performance, especially in mathematics and science, particularly among disadvantaged minorities from urban and rural communities. These disparities start as early as kindergarten, persisting across the secondary grades, and in most cases widen over time.

The achievement performance also differs by family income. At each grade level, in both mathematics and science, students from low-income families have lower average scores and are less likely than students from wealthy families to reach the proficient level. These gaps related to family income are substantial. For example, students from low-income families are at least three times less likely to score at or above the proficient level for their grade in both mathematics and science (NSB, 2006). Low income is measured by whether or not a student is eligible for the free or reduced-priced school lunch program.

Raising academic achievement levels for all students is a top priority for education reform at all levels across the United States. Although improvements have been made, gaps among students of different demographic backgrounds and among schools with different student populations have been a persistent challenge in K–12 education in the United States.

Data from National Assessment of Education Progress (NAEP) indicate that Blacks and Hispanics have shown improvement since 1990, but the 2011 NAEP data show that White and Asian/Pacific Islander students continue to outperform students at every grade level (NAEP, 2011). In both mathematics and science, most 4^{th-}, 8^{th-} and 12^{th-} grade students did not demonstrate proficiency in the knowledge and skills taught at their grade level. Racial/ethnic minority students and students from poor families and disadvantaged backgrounds lagged behind their more advantaged peers, with these disparities starting as early as kindergarten, persisting across grades, and, for some kinds of skills, widening over time (NSB, 2006). Despite the improved performance overall, achievement gaps between these various groups persist and have shown no signs of narrowing since 1990. Black, Hispanic and Native American students in mathematics and science are performing at lower levels than are White and Asian students. In 2011, White students scored higher on average than all other racial/ethnic groups in science. Asian/Pacific Islander and Native Americans/Alaska Native students scored higher on average than Black and Hispanic students, and Hispanic students scored higher than Black students (U.S. Department of Education National Center for Education Statistics, [NCES], 2011). Boys performed slightly better than girls in both subjects.

Overall, large majorities of 4^{th-}, 8^{th-}, and 12^{th}-grade students did not demonstrate proficiency in the knowledge and skills taught at their grade level.

Though a majority of 9th grade students reached proficiency in low-level algebra skills, few mastered higher level skills. Results of international mathematics and science literacy tests show that 15-year-olds continue to lag behind their peers in many countries, even though their scores have improved in recent years (NSB, 2012).

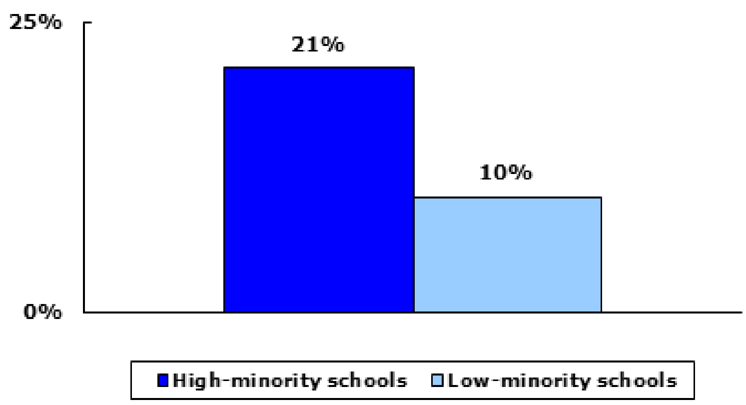
What causes the achievement Gap? The factors are numerous, but some of the strongest factors include poverty, early childhood learning, teacher quality, and strength of the curriculum. There are differences in what happens in schools that are associated with differences in student achievement, including high standards with rigorous curriculum, and qualified and experienced teachers.

Clark (2014) believes the key factors contributing to the achievement gap can be summed up in two words: equity and access. Overall, minority students have less access to: (1) well-qualified science and mathematics teachers, (2) strong science and mathematics curriculum, (3) resources, (4) classroom opportunities, and (5) information.

Less Access to Well-Qualified Science and Mathematics Teachers

Teacher quality can contribute to the achievement gap. Good teaching matters more than anything else, but Blacks and other minority students get less than their fair share of qualified teachers. Minority students get more inexperienced teachers-teachers with three or fewer years of experience. As shown on the table listed below, inexperienced teachers are twice as likely to be in schools with a high level of minority enrollment than in schools with a low level.

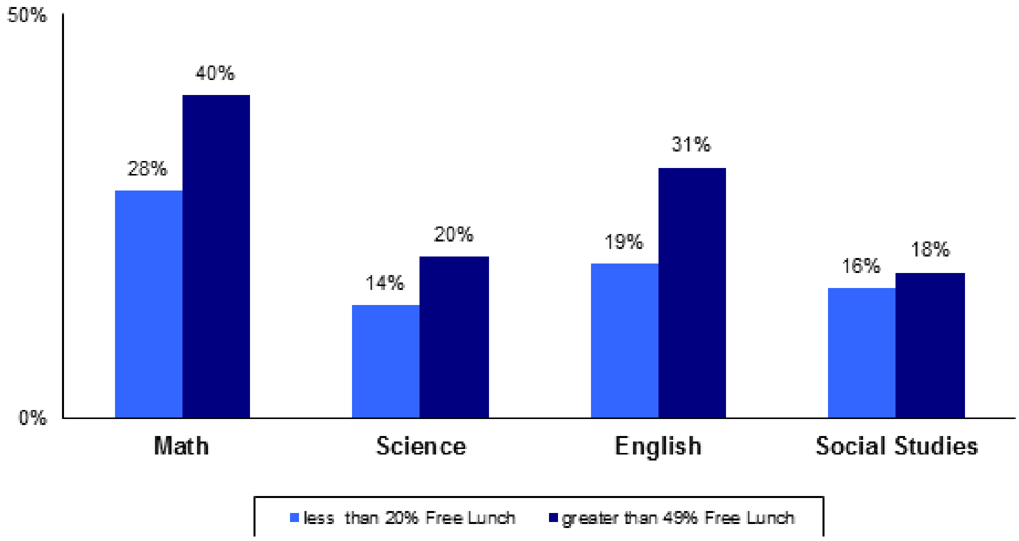
Minority students get more inexperienced* teachers



Teacher with 3 or fewer years of experience. “High” and “low” refer to top and bottom quantities.

Source: *National Center for Education Statistics, “An Indicators Report,” December 2000.*

More classes in high-poverty schools are taught by the least-qualified teach

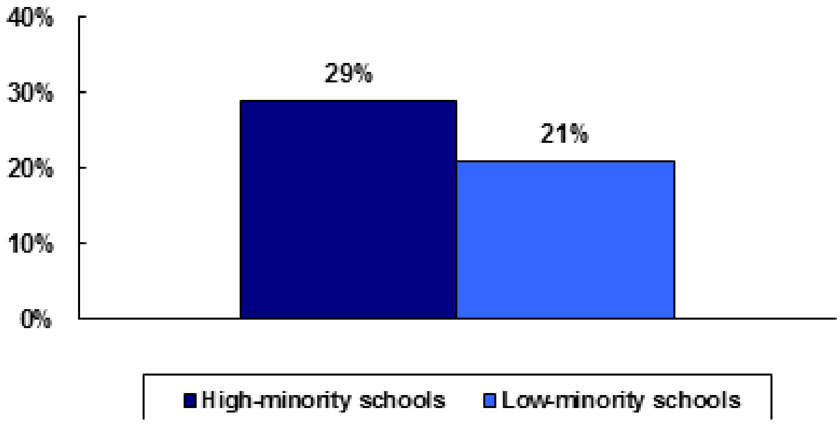


***Teachers who lack a major or minor in the field**

Source: *National Commission on Teaching and America's Future, What Matters Most: Teaching for America's Future (p.16) 1996*

The least-qualified teachers are often assigned to teach minority students. More classes in high-minority schools than in low-minority schools are taught by out-of-field teachers-teachers lacking a college major or minor in the field. High-minority schools contain 50 percent more minority students. Low-minority schools contain 15 percent or fewer minority students.

More classes in high-minority schools are taught by out-of-field teachers*



***Teachers lacking a college major or minor in the field.**

Source: *Education Trust (2003).*

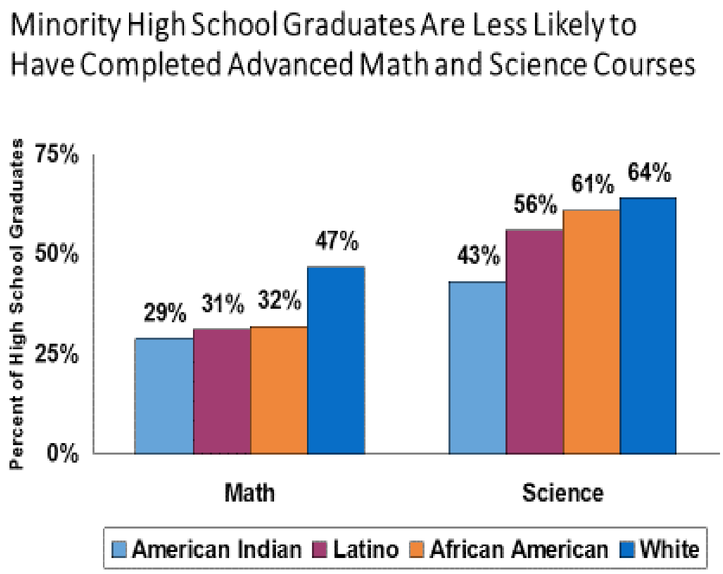
Further, teachers and principals in low-income, high-minority, inner city schools all report problems with teacher interest, motivation, preparation, and competence in science and mathematics instruction. These problems are more evident at the secondary level, where "nearly all types of secondary schools tend to place their least qualified teachers with low-ability classes and their most qualified teachers with high ability classes."

Less Access to a Rigorous High-Level Curriculum

Research shows that students' academic achievement is closely related to the rigor of the curriculum. Poor and minority students have less access to high-level curriculum. Minority students consistently achieve and participate less in mathematics and science and have less access to mathematics and science and high-level curriculum. They experience less extensive and less demanding courses and programs. They are less likely to have completed advanced science and mathematics courses.

Differences exist in science and mathematics taking across racial groups. For example, fewer African American students are enrolled in Algebra II. Whereas 62 percent of white and 70 percent of Asian students had taken Algebra II in 1998, only 52 percent of African Americans, 48 percent of Hispanics, and 47 percent of American Indians had taken this course.

Minority high school graduates are also less likely to have completed advanced mathematics and science courses, and they are less likely to be enrolled in a full college prep track.



Source: U.S. Department of Education, NCES, *Condition of Education 2004*, p 148. Data from 2000 NAEP High School Transcript Study.

Less Access to Resources

Research shows that school districts where low-income, high-minority students are educated consistently receive less state and local money to educate them than do the districts serving the smallest number of minority students. They received approximately $614 less per student per year in 2003 (Education Trust, 2006). Students in low-income, high-minority schools appear to have less access to computers and computer staff, science laboratories, and related resources.

They also lack access to science classes and rigorous science curriculum. Inequities of technology access exist in America's schools. School access, however, does not always mean classroom access, and a digital divide between rich and poor schools still exists. Schools with high minority enrollment have less access to the Internet than do schools with low minority enrollment.

Access to technology is more of a given for white students than for minority students. Data from the U.S. Department of Education, National Center for Education Statistics (NCES, 2000) revealed that Internet access in classrooms varies according to school characteristics. For example, in 1999, 39 percent of instructional rooms had Internet access in schools with a high percentage of low-income students or high concentrations of poverty compared with 62 to 74 percent in schools with low concentrations of poverty.

Less Access to Classroom Opportunities

Teachers of low-income and minority students place less emphasis on essential curriculum goals such as developing inquiry and problem-solving skills. In low-ability tracks, almost all goals are less emphasized, expectations are lower, and instruction is less engaging. There are inequities in school funding. Students from non-white ethnic groups, with the exception of Asian Americans, appear more likely to attend a disadvantaged school, in terms of affluence and resources.

The disadvantaged schools are more likely to have low teacher morale, deteriorating school facilities, fewer materials, lower quality or nonexistent laboratory opportunities, lower student motivation, and fewer certified teachers--especially for science. Nationwide, only about 65 percent of eighth-grade teachers report adequate facilities for laboratory science (NSB, 1996). Performance on the 1996 NAEP in science was higher for students from well-equipped classrooms.

Less Access to Information

School characteristics (such as courses offered and teacher education and experience), student characteristics (such as family income), and mathematics and science course taking all correlated with academic achievement (U.S. ED/NCES 2000c). In addition, national, state, and school district policies regarding teacher qualifications and curricula vary, resulting in differences in access to high-quality teachers and higher-level mathematics and science courses. Low-income, rural and minority parents have less access to information regarding educational opportunities for their children. In summary, factors that contribute to the achievement gap in mathematics and science include inequity in access to qualified teachers, facilities, resources, challenging science, and mathematics curricula for minority students, and too few students taking advantage of advanced coursework.

In the United States different schools have different effects on similar students. Children of color, especially Black and Hispanic students, tend to be concentrated in low-achieving, highly-segregated schools. These minority students are more likely to come from low-income households, meaning that minority students are more likely to attend poorly funded schools based on the districting patterns within the school system.

Schools in lower-income districts tend to employ less-qualified teachers and tend to have fewer educational resources. Research shows that teacher effectiveness is the most important in-school factor affecting student learning (Darling Hammond, 2000, 2014; Akiba, 2014).

In an effort to improve the quality of mathematics and science in U.S. schools and to make mathematics and science accessible to all students, major national reform initiatives have been designed. The United States has initiated several educational policies and comprehensive reform initiatives, such as No Child Left Behind Act; *America COMPETES Act*, and *Race to the Top* to help close the achievement gap among minority and poor students These initiatives have gained wide distribution and have been implemented by a wide range of U.S. schools, universities, industries and science organizations. These are the No Child Left Behind Act (NCLB), America COMPETES Act, and Race to the Top. The federal government targeted funds directly to low-performing schools through the School Improvement Grants program, for example, to support changes needed in the lowest-achieving schools across the nation. No data are available describing the success of these initiatives in narrowing the achievement gap.

The Achievement Gap in Other Countries

Across the globe, education is essential, bettering the lives of individuals and nations from poverty to affluence. Yet educational opportunity and the upward mobility it can bring have not always been equally available to everyone. In rich and poor nations alike, the disadvantaged--defined by gender and geography, race and religion, class and caste--fall behind, losing the chance to improve their lives and depriving society of the contributions they might have made..

As in the United States many countries have developed and implemented unique education models to meet the demands of their students. Almost every education system has been involved in restructuring. School administrators, teachers, students, and parents have found themselves responding to structural, administrative and curriculum changes that governments say will improve the quality of education, and many of these changes have been documented and discussed. Some school districts have shown that all students--regardless of race, ethnicity, income, and background--can achieve at high levels when provided with the appropriate opportunities. Because every culture is different, the contours of the problem vary from place to place. The problem is not uniform. The size of the gaps, the severity of the deprivation, and the identity of the disadvantaged vary from culture to culture.

Everywhere, however, eliminating educational gaps is a complicated endeavor that demands concerted effort from politicians, bureaucrats, teachers, university administrators, and policy makers.

Achievement Gap in Korea

The achievement gap is being addressed in various ways in many countries. High achieving countries-Korea, Singapore, and England have centralized systems of teacher education and certification with tighter regulatory control by the central government. Many countries around the world, like Australia, have centralized teacher hiring and distribution policies.

In Korea inequities in achievement is due to economic disparity and gender inequities. In regard to STEM education, in comparison to students in other countries, Korean students routinely outperform students on mathematics and science standardized examinations In addition, fewer than 6% of Korea's students fail to complete high school and more than 70% of students go on to enroll in two- or four-year university of vocational programs upon completing high school. With regard to access to elementary and secondary education opportunities, there are few discernable differences in either school attendance or academic achievement in terms of gender. However, fewer girls pursue tertiary education than boys and the gender disparity is even greater in graduate and doctoral programs than in undergraduate studies, so fewer women than men are entering the STEM workforce in Korea. National assessments do suggest a developing "gap" in achievement between students in different social class levels and between students living in different regions of the country. Researchers attribute differences in educational advancement between boys and girls to historical gender inequities and differences in achievement is attributed to economic disparities in different regions of the country (e.g., rural versus urban/suburban areas) and between the social classes. Economically disadvantaged families (especially those who tend to live in rural areas) cannot afford private tutoring fees (or access tutors), so these students are not as competitive on the annual national college entrance exam. These gender and class inequalities have their roots in socio-historical, political traditions, which have helped to shape Korea's education system over the last 500 years. In addition to these issues, Korea is facing new challenges with regards to educating an increasingly culturally, ethnically, and linguistically diverse student population resulting from the development of new immigration policies seeking to create an international workforce. (Martin, et al, 2014).

Achievement Gap in Singapore

Many countries, especially Asian countries, have developed and implemented unique models to meet the demands of today's learners. For example, in Singapore the education system is flexible and caters to every child's abilities, interests, and aptitudes so as to help each develop to his fullest potential. It focuses on the development of human resources to meet Singapore's need for an educated and skilled workforce. It also facilitates the inclusion of social moral values to serve as cultural ballast in the face of rapid progress and change. In Singapore, there are disparities in educational outcomes between students of differing demographic characteristics, such as ethnicity and socio-economic status.

In Singapore, there are disparities in educational outcomes between students of differing demographic characteristics, such as ethnicity and socio-economic status. The achievement gap in Singapore is defined largely in terms of ethnicity especially the ethnic Malay minority's persistent educational gaps vis-à-vis the ethnic Chinese majority and socio-economic class. However, official data are often scant, especially in the case of socio-economic gaps. The little data that are available for STEM achievement are based on ethnicity and highlight Malay students falling behind in mathematics and science at the primary level and in mathematics at the secondary level. This is despite the existence over the past three decades of various state-supported Malay community initiatives such as private tutoring schemes to boost overall Malay educational achievement. No evidence is provided about the effectiveness of these initiatives in reducing the achievement gaps. (TAN, 2014).

Achievement Gap in England

There have been various achievement gaps in England over the years – differences in school attainment by students from different socio-economic classes, different genders and different ethnic groups. The achievement gap in England is primarily defined in terms of socioeconomic status. There is a considerable and persistent gap in England in the rates of participation in higher education between those from higher and lower socio-economic groups. The gap is often expressed as the difference between those who are eligible from Free School Meals and the rest of the student population. There are also gender and ethnicity achievement gaps but the political emphasis in England is on closing the socioeconomic status achievement gap. The STEM attainment gap during compulsory education appears driven by similar factors to the general attainment gap, however there seems to have been less progress. More concerning is the gap in the proportions who continue studying STEM subjects in post-compulsory education, particularly between males and females.

There has been more progress in closing the overall socioeconomic status achievement gap in the period between 1997 and 2010, using a diverse range of strategies. Many of these have run counter to the general thrust of increased market competition to drive school improvement.

Although Basil Bernstein, a leading English sociologist of education, argued years ago that "education cannot compensate for society", policy makers continue to believe that education and other social policies can help to equalize school performance and life chances between different social groups. (Whitney, 2014).

Achievement Gap in Turkey

Ensuring students' access to qualified teachers is an important goal of educational policy and reform in many countries. There is a lack of highly qualified teachers, especially in mathematics and science and other STEM fields; low social status and salary of teachers and their poor working conditions (as in Turkey); a lack of systemic induction programs; and inequitable distribution of qualified teachers between high-poverty and low-poverty schools. Many countries show major gaps in students' access to qualified teachers between wealthy and high-poverty students, and White and ethnic minority students. High poverty students and ethnic minority students are twice as likely as wealthy and White students to be assigned novice teachers. They are also more likely to be taught by uncertified teachers, as in Africa and the United States.

In Turkish context, achievement gaps refers to differences of students' mathematics or science achievement depending on educational factors (e.g., school types or students' socioeconomic backgrounds), especially in the national context. These achievement gaps or differences can be observed on individual, group, school, and/or regional levels. In general, Turkey has a large achievement gap-contributed to four major challenges which are all connected: quality differences in school types, competitive nationwide examinations, standardized and teacher-centered science and mathematics teaching from elementary school through college, and the effects of socioeconomic background differences on science and mathematics. There is a need to explore relationship patterns between these challenges.

In Turkey, the number of high school types is very high. While elementary school types are at expected levels (public and private schools) there are more than twenty types of secondary schools. In addition to this school type variability, there are big STEM gaps, in particularly mathematics and science achievement gaps, between these schools. This challenge seems to be the biggest factor widening mathematics and science achievement gap in Turkey. As a solution to narrow differences between high schools, Ministry of National Education (MONE) has started to decrease the number of school types at high school levels.

In 2010, 350 general high schools were converted into Anatolian high schools, and by the end of 2013, all general high schools are going to be Anatolian high schools. In the near future, MONE is planning to convert Anatolian teacher high schools into Anatolian high schools. In the long run, the aim of MONE is to collect similar high schools under one umbrella and to narrow science and mathematics achievement gaps between high schools. (Topeu, 2014).

Achievement Gap in Australia

In Australia the achievement gap is identified in relation to socioeconomic status, Indigeneity and geographical location with students in rural and remote schools generally achieving lower results than their peers attending city schools. Importantly, these three components interact with rural locations having a higher population of Indigenous students and populations with lower SES compared to many affluent suburbs in cities. These achievement gaps have been considered in government policy for educational planning in the past, however access to international data sets like PISA have provided the hard evidence around the extent of this achievement gap. While Australian students compare favorably to most other western countries regarding their scientific literacy, gaps emerge in relation to Indigenous and low SES students. For example, PISA 2009 highlighted that Indigenous students achieved mean score that was 81 points below the Australian mean score whereas students from low socioeconomic backgrounds attained a mean score 96 points below the Australian mean. Unfortunately, these gaps are substantive equating to between 2-2.5 years of schooling with an equivalent gap identifiable for PISA 2009 mathematics.

Attempts to close gaps in Aaustralia has small beginnings of success. For example:

- Emphasis on quality teaching for all students with a focus on dealing with diversity within the classroom.
- Targeted programs for students from Indigenous and low SES backgrounds linking them with universities-evidence of traction but still early days.
- Special funding to universities for the inclusion of students from low SES and Indigenous backgrounds.
- Focus on increasing students from these backgrounds into teacher education to provide role models-again, early days but there is evidence of improvement. (Panizzon, 2014)

Achievement Gap in China

Education inequality exists everywhere, and China is no exception. However, the achievement gap in China takes entirely different forms and has different causes than that in the United States. Achievement gap in China is not primarily an ethnic one. Over 90% of China's population is ethnically Han. The achievement gap in China is geographical, economical, and political. China's achievement gap is influenced by economic facto. For example, education in Western China is generally of lower quality than that in more developed eastern provinces of China. Children in rural areas are much more likely than those in the cities to drop out of school and to have fewer opportunities to attend college. The national hukou system, a way to manage population based on their place of birth, has been another powerful cause of the gap.

In China, achievement has been narrowly defined as the Gaokaao scores. The unequal educational opportunities are marked between urban and rural areas, between the Eastern and the Central/Western regions, and between more and less prosperous provincial areas. In contrast with the United States, where race/ethnicity is the primary concern for the achievement gap, ethnicity is a much smaller factor in China. Instead, both the general achievement gap and STEM gap in China are influenced by economic favors. But more important, both gaps are the product of social, political and historical factors such as the Hukou requirement, the quota system, and policies of school choices.

China has intentionally created an educational system that deliberately celebrates achievement gaps based on meritocracy. China has undertaken numerous efforts to address the inequalities in education, out of national economic and political concerns. (Zhang and Zhao, 2014).

Achievement Gap in South Africa

Reforms are underway in South Africa to deal with the achievement gap between advantaged and disadvantaged students. Poor communities, in particular those of rural Africans, bear the brunt of its past inequalities. South Africa's focus is on Apartheid that created racial discrimination/segregation, fiscal inequality. At the height of the apartheid era, public spending on white children was around 5 times the amount for Africans. South Africa has participated in seven cross-country comparative studies and the results were South Africa performed poorly compared to many of its more impoverished neighbors, and very poorly in relation to developing countries in other parts of the world. Poorer children receive schooling inferior to that of their more affluent peers. There are continuing large disparities in the outcomes produced by different kinds of school linked to past racial affiliation. (Taylor and Muller, 2014).

Achievement Gap in Mexico

There is an inequality gap of the great cultural and socio-economically diversity of the Mexican population, characterized for the large differences among those more or less marginalized, with a very high percentage of population in poverty and a high percentage in extreme poverty. There is concern on the achievement of students in rural, urban of high marginalization, and urban of low marginalization. By addressing this concern, it is hopeful that improvement toward closing the gap will occur. (Sanchez Martinez, 2014).

Achievement Gap in Canada

Socioeconomic status in high-poverty communities is an issue Canadians having been dealing with in closing the gap. A concern of Canada public education is that of achievement differences in national, provincial/territorial, or group performance. In Canada there is an inter-provincial, gender, and indigenous status gaps. The critical issue for Canada has been the engagement and performance of indigenous students (male and female). Canada has used international, national, and provincial (BC) test, participation, and graduation data to identify gaps across nations, provinces, schools, gender, and ethnicity (indigenous/non-indigenous). The nation and province difference are apparent but not super interesting. The gender difference of the past have closed to where females perform as well or better than males, except their participation in mathematical sciences in post-secondary level remains less than males. This is critical for the STEM pipeline issues. Attention is given to language arts, science, and mathematics. Technology and engineering are not a central part of the school curriculum in most provinces. To assist in closing the achievement gap, post-secondary institutions in BC participate in a program that provides scientist, engineers, technologists, and mathematicians as speakers for schools. The University of Victoria and other university have offered informal or extra-curricular in summer camps, after school, and Saturday programs on STEM to encourage and interest girls and boys in these disciplines and future careers. Similar events and internships have been offered during the Pacific CRYSTAL and other projects to allow young indigenous people to learn their IKW and transition to WMS. These projects have real potential, but they are small in number and recent arrival in STEM education platform. Clearly, the New Framework for Science Education K-12 (NRC, 2012) recognizes that science and engineering practices will provide a justification for more in and out of school opportunities like these for indigenous and non-indigenous girls and boys. (Yore, 2014).

Achievement Gap in Brazil

In Brazil, the achievement gap focuses on the prevalence of socio-economic differentials between Black and White Brazilians. There is the persistence of gaps in the quality of education provided to Blacks and Whites. In Brazil, test scores in the southeast top those in the northeast.In the United States graduate from high school at far lower rates than their White and Asian peers.

Around the world, in countries rich and poor, some groups succeed educationally – attending school, earning high grades and test scores, completing college degrees –

whereas others struggle, for a complex mix of historical, cultural and economic reasons. (Rangel & Madeiria, 2014)

Summary

Research conducted around the world shows inequity to qualified teachers, facilities, resources, challenging mathematics and science curricula, and opportunities; and too few students enrolled in advanced coursework all contribute to the achievement gap in mathematics and science. School characteristics such as family income and mathematics and science course taking are all correlates of academic achievement. In addition, policies regarding teacher qualifications and curriculum vary from country-to-country, resulting in differences in access to high-quality teachers and higher-level mathematics and science courses. For example, high achieving countries-Korea, Singapore, and England, have centralized systems of teacher education and certification, with tighter regulatory control by the central government. Singapore and Korea have built strong education systems creating productive teaching and learning systems by expanding access while investing purposefully in ambitious educational goals using strategic approaches to build teaching capacity. Some countries, like Canada, have raised their test scores and high graduation rates in Canadian schools by providing more resources.

Australia is focusing on ways to improve the socioeconomic status in relation to the achievement of secondary science and mathematics students. Australia is also looking at ways to ensure that schools are empowered in a sustainable way Many countries like Australia also have centralized teacher hiring and distribution policies. Turkey is also looking at quality differences in school types and teacher effectiveness. Poverty and unequal resources and unequal distribution of curriculum and teachers are serious in some of the countries such as Mexico, the United States, and Brazil. Low-income children are much less likely to have access to early learning opportunities than their more affluent peers. These inequalities translate into disparities in the number of qualities and other educators, and to unequal access to high quality curriculum. Teachers in high need schools have an average lower levels.

England describes how they narrow the socio-economic achievement gap in England under its New Labor Government in an effort to equalizing school performance. Turkey has recently science and mathematics reforms built on the Ministry of National Education (MONE) student-centered and flexible learning and teaching methods instead of standardized teaching. Brazil is exploring unique ways of eliminating racial disparities in socio-economic outcomes in Brazil. Reforms are underway in South Africa to deal with the achievement gap between advantaged and disadvantaged students. Poor communities, in particular those of rural Africans, bear the brunt of its past inequalities. Government has embarked on a strategy in the interests of improving quality in poorly performing majority schools, strengthening school supervision, holding schools accountable for the performance of their learners, and strengthening initial teacher training.

In the United States, there are two achievement gaps in its education systems. The first of these – well-documented, widely discussed, and the focus of education reform efforts for the past decades or longer - is the gap between the quality of schooling that most middle class children (wealthy) gets in America and the quality of schooling available for most minority and poor children – and the consequent disparity results. The second one is the global achievement gap – the gap between what even our best suburban, urban, and rural public schools are teaching and testing versus what all students will need to succeed as learners, workers, and citizens in today's global knowledge economy. There is also a large gap in STEM education in the United States compared to many countries. Achievement in the United States since its founding has been concentrated in just a few places, which has created a gap that correlates with economic and educational disparities observed today.

The commonality that exists in the achievement in most of the countries is socioeconomic status. A very important concern is the level of education and inequitable distribution of support to schools in low income and minority communities. Low-income children are much less likely to have access to STEM and other learning opportunities than their more affluent peers. Economics is a critical determinant to access. To improve student achievement and opportunities demands access and equity

Concluding Remarks

Across the globe, in both rich and poor nations, education is essential and it is the key to developing the intellectual capacity of our children. Nothing is more vital to our country's future than ensuring that all students receive a quality education. Gains in student achievement can most likely be realized wherever along the development continuum the effort is made.

The success of education in this century and the century to come will depend on the extent to which we educate all of our children and the achievement gap is closed so that No Child is Left Behind..

The level of education and inequitable distribution of support to schools in low income and minority communities is a very important concern in many of the countries Economics is a critical determinant to access. To improve student achievement and opportunities demands access and equity. Education provides the basis for infrastructure development, adequate sustenance, health care, healthy and sustainable environments, civic and social order and growth, and productive civil order and growth, and productive civil and international relations.

Several countries have shown that access and equity are compelling factors in closing the achievement gap. Providing all students (rich and poor, male and female, Black, Hispanic, Native Americans, Indegenous, and other ethnic groups) with well-prepared and qualified teachers, adequate funding and resources, rigorous mathematics and science curriculum, opportunities with high expectations, will go a long way to promoting excellence and in closing the achievement gap.

Data from the various countries suggest several conclusions. First, they confirm that socioeconomic status is a strong and consistent determinant of academic achievement in all countries and contribute to the achievement gap. The issues of access, equality and equity are important concerns in education reform and become salient political concerns. In practice, however, in many countries, the children who most need an extra educational boost are the least likely to get it. Lower-quality schooling appears to help perpetuate inequality rather than combating it.

The time is ripe for a concerted effort to improvement the achievement of all of our students. By focusing our attention on closing the achievement gap, with immediate attention to STEM, we will be able to give local, State, and Federal educational agencies a call for action that is substantive, timely, and sufficiently targeted that it is reasonable to anticipate progress.

We live in an era in the history of nations when there is a greater need than ever for coordinated political action and responsibility. Collaboration between the various countries, learning from each other, and sharing with each, can serve to elevate an international dialogue on the critical issues associated with the achievement gap and provide concrete examples to foster a solution. New ideas coming from other countries, and having other countries understand and learn from each other, can help in transforming education and in the closing of the achievement gap.

It is the hope that the findings and analysis and the overall issues of the achievement gap will benefit not only the further development of each region but also other international communities. Perhaps most importantly, all the countries will keep the goal of closing the achievement gap and raising the achievement performance of all the children in STEM at the forefront of their attention. In this way, we would be working together to solve a problem of global significance.

Disclaimer:

The views of this manuscript are those of the author and not those of the National Science Foundation (NSF)

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Promoting STEM Education for All Students

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The American Association for the Advancement of Science (AAAS) reports *Project 2061: Science for All Americans* (1989) and *Benchmarks for Science Literacy* (1993) as well as the National Research Council (NRC, 1996) in the *National Science Education Standards* (NSES) emphasize the importance of science and technology. These social aspects of science and technology are a form of content for K-12 science. The Standards state that, "a person should be able to identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed" (NRC, 1996, p.22). These reports also describe the relationship among science, technology, and society. "Science and technology are closely related. A single problem often has both scientific and technological aspects (NRC, 1996, p.24). The AAAS Benchmarks also state that "Technology usually affects society more directly than science because it solves practical problems and serves human needs. Science affects society mainly by stimulating and satisfying people's curiosity and occasionally by enlarging or changing their views of what the world is like" (AAAS, 1993, p. 45).

The National Science Education Standards also emphasize a goal that students should achieve scientific literacy, which is defined as the knowledge and understanding of scientific concepts needed for daily living. The National Science Teachers Association declares that a scientifically literate person is one who can ask and determine answers to questions derived from curiosity about everyday life experiences (NSTA, 1996). Rutherford and Ahlgren, authors of <u>Science for Americans</u>, state that " the world has changed in such ways that scientific literacy has become necessary for everyone, not just a privileged few; science education will have to change to make that possible" (AAAS, 1993; Hollenbeck 2003). Bybee (1993) suggests that students should learn basic concepts of science, process, and problem-solving skills, and the interactions of STS as they apply their knowledge to real-life concerns and issues (Lumpe, Haney & Czerniak, 1998).

Scientific literacy enables people to not only use scientific principles and processes in making personal decisions but also enables them to participate in discussions about scientific issues that affect society. Scientific literacy increases many skills that people use in everyday life, like being able to solve problems creatively, thinking critically, working cooperatively in teams, and using technology effectively. Understanding scientific knowledge and processes contributes in essential ways to developing these skills. The economic productivity of society is related to the scientific and technological skills of the people. However, achieving scientific literacy will take time, because the

National Science Education Standards call for dramatic changes in what students are taught, how student performances are assessed, how teachers are educated and stay current, and the complex relationships between school and community (NRC, 1996). Ramsey (1993) suggests that there is a relationship between scientific literacy and social responsibility. Merely memorizing facts for a science test is not sufficient in a world in which background of scientific and technologic knowledge is imperative for making decisions on personal, community, national and global levels.

A focus on the relationship among science, technology, and society is essential for achieving basic science literacy. Students, the next generation, need to be able to analyze evidence, to understand the relevance of science based issues to their everyday lives, and to understand that the scientific endeavor is governed by social values (NRC, 1996; deBettencourt, 2000). Seventeen features are identified by NSTA to define quality of scientifically literate person. These features include being able to:

- Use concepts of science and of technology as well as an informed reflection of ethical values in solving everyday problems and making responsible decisions in everyday life, including work and leisure;
- Engage in responsible personal and civic actions after weighing the possible consequences of alternative options;
- Defend decisions and actions using rational arguments based on evidence;
- Engage in science and technology for the excitement and the explanations they provide;
- Display curiosity about and appreciation of the natural and human-made world;
- Apply skepticism, careful methods, logical reasoning, and creativity in investigating the observable universe;
- Value scientific research and technological problem solving;
- Locate, collect, analyze, and evaluate sources of scientific and technological information and use these sources in solving problems, making decisions, and taking action;
- Distinguish between scientific/technological evidence and personal opinion and between reliable and unreliable information;
- Remain open to new evidence and the tentativeness of scientific/technological knowledge;
- Recognize that science and technology are human endeavors;
- Weigh the benefits and burdens of scientific and technological development;

- Recognize the strengths and limitations of science and technology for advancing human welfare;
- Analyze interactions among science, technology, and society;
- Connect science and technology to other human endeavors, e.g., history, mathematics, the arts, and the humanities;
- Consider the political, economic, moral, and ethical aspects of science and technology as they relate to personal and global issues;
- Offer explanations of natural phenomena which may be tested for their validity (NSTA, 1990).

Scientific Literacy

Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. In the National Science Education Standards, the content standards define scientific literacy as following; scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (NRC, 1996)

Scientific literacy is important for two views. The first one is macro view that promotes scientific literacy that includes benefits to national economics, science itself, science policymakers, and democratic practices, as well as to society as a whole. Second one is micro view that turns to the direct benefits of scientific literacy to individuals, it has been suggested that improved understanding of science and technology is advantageous to anyone living in science and technology dominated society.

Bybee (2013) clearly articulates that the overall purpose of STEM education is to further develop a STEM literate society. His definition of “STEM literacy” refers to an individual’s:

- Knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues.
- Understanding of 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; and
- Willingness to engage in STEM-related issues and with the ideas of science, technology, engineering and mathematics as a constructive, concerned, and reflective citizen.” (p.101).

What is STEM education and why do we need it?

Although STEM education have attracted attentions of thousands of researcher from all over the world recently, it has its origins in 1990s (Bybee, 2013). There are different views about it. In their study, Breiner and colleagues (2012) found that there is not certain definition or conceptualization of STEM even among faculty members. Whereas some part of researcher think that STEM education occurs when integrating science, technology, engineering and mathematic curriculums to familiarize students about how scientists and engineers work in their real context, some other advocate that the goal of STEM education is to direct students into sub-branches of it in order to have qualified scientists and engineers in the future and to be competitive among developed and developing countries (Breiner, Harkness, Johnson & Koehler, 2012). In general, it can be said that STEM education enables students to produce products through multidisciplinary knowledge. STEM education is the intentional integration of science, technology, engineering, and mathematics, and their associated practices to create a student-centered learning environment in which students investigate and engineer solutions to problems, and construct evidence-based explanations of real-world phenomena with a focus on a student’s social, emotional, physical, and academic needs through shared contributions of schools, families, and community partners.

There are two main ideas behind STEM education, one of which is about political and societal reasons and the other one is educational deficiencies. In political and societal perspective, nations need an innovative STEM workforce to be competitive in the 21st century (Corlu, Capraro & Capraro, 2014, p. 75). When the US realized this fact, they launched the STEM project more accurately. Innovations in science and technology will give rise to be competitive for countries in this century and one of the major ways for such innovations seems as educating students through STEM education. The National Academies of Sciences, Engineering and Medicine (2011) state that innovations in science and technology mainly results of developments in science, technology, engineering and mathematics. In another report published by the Committee on Prospering in the Global Economy of the 21st century (2007), it is stated that for the nation's welfare and well-being, STEM skills should be focused much more and three major advices were published in the report. These are (1) augmenting the number of successful students in science and mathematics at K-12 level through developing teaching strategies for that level, (2) supporting the projects about security and quality of life and (3) increasing the prompts for innovation (Committee on Prospering in the Global Economy of the 21st century, 2007). There are a lot of reports (e. g. U.S. Commission on National Security/21st Century, 2001) which emphasize that focusing on science, technology and mathematics are crucial for economic growth, the nation's development and security and competitiveness among other developed and developing countries.

In terms of educational deficiency viewpoint, in traditional teaching approaches it is common to teach the subjects separately. In other words, there is less emphasis on the connections among disciplines. In STEM education, the important concept is 'integration'. Integrating science, technology, engineering and mathematics is vital cornerstone of it. For instance, an engineer needs different scientific disciplines knowledge and mathematics and technology information in order to produce highly qualified engineering designs (Breiner et al., 2012). This can be achieved by STEM education easily, which requires integration of various disciplines. This lack of integration in traditional teaching approaches necessitated STEM education as a powerful approaches in educational context. The following tables identify several points of contrast between STEM-based program and standard (traditional) science programs concerning goals, instruction, teacher, students and evaluation. Table 1 indicates the differences between STEM-based program and traditional science program in terms of the goals of science education.

Table 1. Contrast between STEM-based and Traditional Classrooms –Goals

STEM-Based Classrooms	Traditional Classrooms
Curriculum is problem-centered, flexible, and culturally as well as scientifically valid Multifaceted questions used as organizers, often with local and community relevance Use of natural environment, community resources, and students themselves as part of the study Information is in the context of the student as a person in cultural/social environment	Curriculum is textbook-centered, inflexible; only scientific validity is considered Textbook controlled; student questions often ignored because the course structure is set Contrived materials, kits, classroom bound resources Information is the context of the logic and structure of the disipline

Table 2 indicates the differences between STEM-based program and traditional science program in terms of the instructional model of science education

Table 2. Contrast between STEM-Based and Traditional Classrooms-Instruction

STEM-Based Classrooms	Traditional Classrooms
Student centered Individualized and personalized, recognizing student diversity Cooperative work on problems and issues Students are considered in instruction (active partners) Teachers build on student experiences, assuming that students learn only from their own experiences	Teacher centered Some group work, primarily in the laboratory, following textbook directions Students seen as recipients of instruction Teachers ignore students in terms of what they might bring to the instructional process; use information assumed to follow rote learning

Table 3 indicates the differences between STEM-based program and traditional science program in terms of the role of science teachers.

Table 3. Contrast between STEM-Based and Traditional Classrooms- Teachers

STEM-Based Classrooms	Traditional Classrooms
Teachers are seen as model learners Teachers exercise freedom to stimulate student interest and involvement Teachers have a well-thought out research based rationale for teaching science Philosophical position influences all aspects of curriculum planning and teaching practices	Teachers are seen as disseminators of information Teachers see their role as delivering content and determining the exact structure of their courses Teachers typically do not have a research based rationale for teaching science Curriculum and teaching practices generally routine

Table 4 indicates the differences between STEM-based program and traditional science program in terms of the role of students in science classroom

Table 4. Contrast between STEM-Based and Traditional Classrooms- Students

STEM-Based Classrooms	Traditional Classrooms
Students are at the center of classroom Students are more active, involve in real life problem solution Students can transfer their learning to their daily living and to meeting social needs Students extend the classroom activities outside the school Students indicate interest Students question more; student question used	Students are recipients of what the teachers dictates Students involved in directed activities unrelated to their own lives There is no demonstration of the use of information taught and learned outside the classroom Students rarely practice or think science outside the science classroom Student express lack of interest in science classes Students questions less; student questions often ignored

Table 5 indicates the differences between STEM-based program and traditional science program in terms of the student evaluation in science classes.

Table 5: Contrast between STEM-Based and Traditional Classrooms- Evaluation

STEM-Based Classrooms	Traditional Classrooms
Testing and evaluation stress the use of concepts and processes to interpret personal and social problems and issues Student evaluation is based on growth in rational decision-making Creativity skills and positive attitudes are stressed and used for assessment	Starting correct solutions to preplanned problems is focus Application is rarely approached in teaching and evaluation Typical assessments do not facilitate development of creativity skills nor positive attitudes Assessment is often provided by external examiners or by textbook authors

Why do we need STEM?

Integrated education, such as STEM, has enormous benefits for students (Stohlmann, Moore & Roehrig, 2012). It has an impact on students' problem solving skills, develops higher order skills and support deep understandings (c.f. Stohlmann et. al, 2012). Specifically, STEM education enables learner to be innovative and problem solver, logical thinkers, to use technology appropriately and effectively (Morrison, 2006). In their study, Basham and Marino (2013) state that STEM learning forces students to use higher order thinking skills instead of lower ones such as calling knowledge in a simple form. Out of the effects of STEM education on students' cognitive skills, the other crucial acquisition of it is that it enables students to get familiar with and to experience engineering design, which is important for developing solutions about the problems in society (Basham & Marino, 2013) such as air pollution, traffic jam and so on. Bybee (2013) summarizes four main points between STEM education and other educational approaches. These are

- Addressing global challenges that citizens must understand
- Changing perceptions of environmental and associated problems
- Recognizing 21st century workforce skills
- Continuing issues of national security (Bybee, 2013, p. 33).

To sum up, STEM education tries to find solutions for problems mainly related with real life context-based issues. It is believed that educating learners based on this approach, and then the nation's welfare and competitiveness will increase in international context. The reasons behind this view are that STEM education help students to develop their higher order skills, creativity and understandings.

How do we integrate STEM in schools / How do we prepare STEM curriculum?

Project based learning and inquiry learning might be two main teaching methods in STEM curriculum. In such learning environments, curriculum materials should be appropriate with the teaching methods (Baran, Canbazoğlu-Bilici & Mesutoğlu, 2015). The crucial point is that enabling students to act as real scientists such as generating products through discovery learning techniques.

One of the efficient ways to provide STEM education in schools is that increasing usage of information technologies (Ministry of National Education, 2016). MNE (2010) launched FATIH project (Action of Enhancing Opportunities and Improving Technology) and encouraged teachers to use EBA (Educational Informatics Network). Both of them provided interactive boards, internet connection and tablet computer for students and teachers. The importance of technology enhanced learning environments can be explained that it provides opportunities like problem determining to research, data collection and analyze, product development and creating new inventions and designing innovations (MNE, 2016). On the other hand, usage of information technologies also provides opportunities for everyone in the classroom, which is important for promoting STEM education for all students. In the report published by MNE (2016) summarizes the importance of technology enhanced learning environments in STEM education as following:

- Facilitating STEM education which is based on questioning, researching, product development and inventing,
- Providing an environment to students independent from time and location for STEM education,
- Supporting STEM education by using digital multimedia laboratory materials,
- Providing equal opportunities in STEM education for children at socioeconomically low and high background, and
- Helping students to learn with lesson activities based on questioning, researching, product development and inventing (NME, 2016, p. 54).

Furthermore teaching coding in computer systems is another crucial step in STEM education for students in order to development technologically developed products.

All these need highly educated teachers to reach the goals through STEM education. For this reason, universities and NME should increase the collaboration for helping teachers to get familiar with usage of technology in classrooms in terms of pedagogic approaches. For example, in US, there are high collaborations between universities and the primary, middle or high schools to develop and apply qualified STEM curriculums (Stohlmann, Moore & Roehrig, 2012).

Conclusion

Although STEM education has roots from last decade, it attracted scholars' attention mainly in the last 10 years. The primary reason of being popular in recent term is usually related with U.S policies. In other words, to have competitive generations in future among developed or developing countries, it is believed that STEM education helps learners in order to be innovative, problem solver, designer and producer. There have been conducting many researches, which usually concluded with supporting the view. Students, who expose to multi-disciplined teaching approach, like STEM gives better result when compared to their counterparts in terms of productivity, innovative outcomes and accomplishment. Such findings also supported STEM education to be used in different regions and countries.

In other respect, it is important to provide equal opportunities for students so as to take advantage of STEM education abundantly. One of the efficient ways is that using information technologies in the classrooms. Technology enhanced learning environments enable learners and teachers to determine problem, data gathering and analyzing, visualization and designing easily. Information technologies also serve as time and location independence.

The other crucial point in STEM education is that teacher education. Because of the fact that teachers are mainly responsible for teaching in the classroom, it is vital to have qualified teachers in terms of STEM education. Teachers should be aware of integration of different disciplines through teaching process and should act as guidance in the classroom. In order to help teachers, universities and schools should increase collaboration and teacher should be supported through workshops and in-service teacher education activities.

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SECTION 4
AN OVERVIEW OF THE LITERATURE ON STEM EDUCATION

Active Learning in Undergraduate STEM Education: A Review of Research

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Introduction

Traditionally, the college classroom has been a place where professors lecture and students are expected to listen and learn with little to no participation. However, there has been a movement toward transforming the college classroom to foster dynamic student centered learning. This shift is particularly significant for college students in pursuit of science, technology, engineering, and mathematics (STEM) degrees since the ability to apply the knowledge and theory learned in the classroom is important to success in their future careers.

In recent years, there has been increasingly more focus on STEM education from a national perspective (Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012). Consequently, it is important for our youth to be equipped with the knowledge and skills to solve challenging problems, gather and evaluate information, and interpret data. These types of skills are acquired by studying science, technology, engineering, and mathematics, subjects collectively known as STEM (U.S. Department of Education, 2015). However, the number of students who pursue, persist, and complete degrees in STEM is low. In fact, based on national college and university statistics, only about 40% of students who plan to complete a degree in a STEM area actually do so (President's Council of Advisors on Science and Technology, 2012). As a result, nationally there is a lack of STEM professionals, which leaves us with less talent available to be innovators of science and technology.

When students are taught to think deeply, they have opportunities to become the future innovators, educators, researchers, and leaders in our country and the world. But, according to a recent report by the U.S. Department of Education, not enough of our youth have access to quality STEM learning opportunities and too few students see these disciplines as potential career paths. For example: 81% of Asian-American high school students and 71% of white high school students attend high schools where a full range of STEM courses are offered. However, the access to this type of education is limited for American Indian, Native-Alaskan, Black, and Hispanic high school students

(U.S. Department of Education, 2015). Since many students do not have access to a variety of science and mathematics courses in kindergarten through twelfth grades, when they enter college they are not necessarily college ready or prepared to thrive in college level STEM education. Therefore, it is critical to improve k-12 education and to implement instructional strategies at the collegiate level to enhance the learning and educational opportunities of every student, including those from underrepresented groups in order to prepare them for a modern STEM economy.

Minority serving institutions (MSIs), like Hispanic Serving Institutions (HSIs) and Historically Black Colleges and Universities (HBCUs) are very important in training the next generation of scientists, particularly those who are from underrepresented groups. Specifically, HBCUs are positioned to meet the STEM challenge as "engines of economic growth and ladders of advancement for generations of African Americans" (U.S. Department of Education, 2016). In fact, for more than a century, HBCUs have been frontrunners in educating African-American college graduates who excel in their fields. Even though our nation's HBCUs make up only 3% of the colleges and universities, they produce 27% of African-American students with bachelor's degrees in STEM fields (U.S. Department of Education, 2016).

In 2012 the President's Council of Advisors on Science and Technology developed a report on the state of STEM in America entitled, "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics". Overall, this article emphasized the importance of increasing the number of graduates in STEM areas in order to maintain scientific preeminence in the United States of America. This report specifies challenges that must be addressed in our college and university classrooms. Three recommendations were highlighted in the report: improve the first two years of STEM education in colleges/universities, provide all students with the tools and resources they need to excel, and diversify pathways to STEM degrees (President's Council of Advisors on Science and Technology, 2012).

It is a known fact that sometimes the course content in STEM classes is challenging, but the learning environment can have a major impact on student interest and motivation. As a result, many students leave STEM disciplines before they can realize their potentials (Petrillo, 2016). Studies have shown that teaching techniques that engage students as active participants improve retention of information and critical thinking skills and can greatly increase STEM major interest and persistence, compared with traditional lecture (President's Council of Advisors on Science and Technology, 2012).

Figure 1 highlights some of the major factors that impact student success in STEM courses at the collegiate level. As indicated in Figure 1, there are several factors that influence student overall performance and success in college level STEM courses.

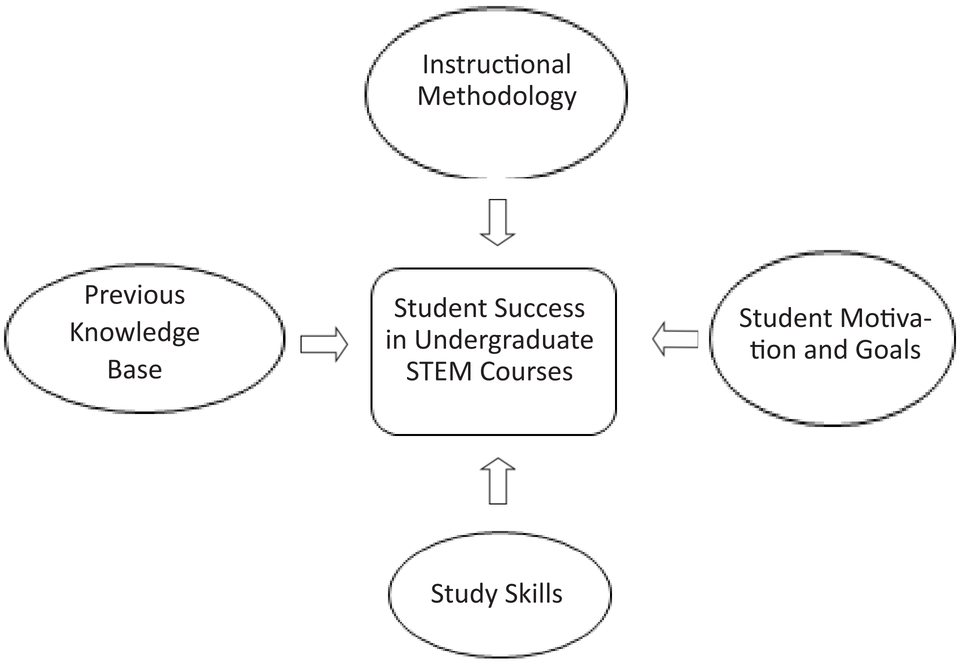

Figure 1. Major Factors Impacting Student Success in Undergraduate STEM Courses

The teaching methodologies utilized by professors can also have a positive impact on the other major factors that influence student academic success in STEM. The focus of this paper is the instructional methodology implemented by the professor, specifically active learning techniques.

Despite what the research has shown about the positive effects of student engagement on student learning, lecture remains the primary method of instruction in college classrooms. This style of teaching is referred to as "teaching by telling" because it involves an instructor centered approach (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014). This technique requires little to no participation by the student during class time. As a result, the professor does not receive immediate feedback about the student knowledge base or his/her level of understanding of the course material. In addition, traditional lecture often fails to encourage intellectual engagement which is an important hallmark of college education (Smith, Sheppard, Johnson, & Johnson, 2005). Therefore, lecture with minimal student participation may have the unintended consequences of stifling a student's progress and diminishing a student's confidence in his/her ability. While lecture is still an important component of classroom instruction, it should be supported by student centered instructional strategies.

Classroom environments in which students are given opportunities to participate in science and mathematical investigation, communication, and group problem-solving, and simultaneously receiving feedback on their work from both professors and peers, have a positive effect on learning (Conference Board of the Mathematical Sciences, 2016). Teaching techniques that include these types of activities are called active learning methods. Based on a variety of studies, these methods have been shown to strengthen student comprehension and performance in STEM courses, to enhance students' confidence in their ability to do science and mathematics, and to increase the diversity of the STEM community (Conference Board of the Mathematical Sciences, 2016).

One way to improve the first two years of college STEM education is through enhanced instructional strategies, which actively include the student in the learning process. As a result, some college professors have developed and utilized more teaching strategies which engage students in the learning process. One prominent methodology is active learning.

The term "active learning" as it is currently interpreted dates to the early 1990s and the work of Bonwell & Eison (1991), building on the work of Revans (1983) (Conference Board of the Mathematical Sciences, 2016). Researchers have investigated the relative effectiveness of various classroom strategies that complement other elements of effective teaching. These include the following: well-designed courses with goals and learning outcomes clearly communicated to students, allowing students to learn new material and make connections with previous knowledge, and giving students timely feedback about their work and thinking related to the course content (Fink, 2013).

In this paper, we examine the literature that considers active learning in STEM education. We do this in three main sections, aiming to: (a) define some of the major active learning teaching techniques; (b) highlight key STEM active learning studies conducted; and (c) discuss the impact of active learning in STEM education on diverse student populations.

Definitions

In recent years, there have been many studies supporting a move toward active learning in college classrooms, particularly in STEM education. Active learning is a broad term that encompasses several models of instruction, including cooperative and collaborative learning, problem based learning, inquiry based learning, discovery learning, and experiential learning (Barkley, 2010). It is a process of education whereby students engage in activities, like reading, writing, discussion, or problem-solving that encourage analysis, synthesis, reflection and evaluation of class content. Active learning techniques have been shown to improve student retention of information while critical thinking skills, which result in an increase in STEM major interest and persistence compared to traditional lecture based instruction. Overall student engagement typically increases the success rate of students in college classrooms. We highlight some of the strategies used when active learning techniques are implemented into a course.

Cooperative learning is also called peer-team learning and it benefits students in several ways. This teaching technique involves structuring classes around small groups of students that work together to pursue common goals while being assessed individually (Prince, 2004). Cooperative learning should: (i) provide students with a supportive environment where they can asks questions, (ii) engage students in discussions that will help them understand important concepts, (iii) encourage students to participate in teamwork which will benefit them in the future, (iv) allow students to develop better communication skills, and (v) support peer leaders in gaining important teaching and leadership skills in a safe environment.

Problem based learning (PBL) is a student centered instructional approach that empowers students to conduct research, combine theory and practice, and apply knowledge and skills to develop a viable solution to a well-defined problem (Savery, 2015). This approach is most successful when the problems selected are interdisciplinary yet not well structured and the professor guides the learners through the process and gives a thorough summary at the end of the learning experience. It is an instructional method where relevant problems can be introduced at the beginning of the lesson and used to provide the context and motivation for the learning that follows (Prince, 2004). This type of learning may be extremely beneficial for a student majoring in STEM, especially engineering, because it helps them make the connection between the theory learned in class and the practice/application of those skills on real-life problems. Students who engage in PBL usually acquire skills, such as the following, the ability: (i) to think deeply and critically, (ii) to analyze and solve multipart problems, (iii) to work cooperatively, (iv) to effectively communicate their knowledge, and (v) the skill of maximally utilizing the resources available.

One prominent method used across STEM disciplines is inquiry based learning (IBL). IBL includes a range of educational methods that allow the student to demonstrate curiosity and answer questions through an active process of exploration. This technique can be utilized in one particular instance, over a short period of time, or throughout an entire course and can be done individually or in small groups (Haq, 2017). This particular methodology can be implemented with or without the use of technology. One popular technology tool that has been widely used is clickers. This can be done by creating sets of multiple choice questions for students to respond to during the class lecture using clickers. This is a good opportunity for the professor to gain some feedback about each student's level of understanding and it is also a way for the students to check their knowledge.

IBL can also increase the student's ability to use prior knowledge and newly acquired knowledge to solve problems, build student confidence in his/her ability, and develop the student's teamwork skills.

A modern technique that some professors are using in an effort to improve classroom instruction is called the flipped or inverted classroom. Flipping refers to the process by which a professor disseminates course content prior to and outside of the classroom and then uses class time to implement a variety of active learning techniques (Petrillo, 2016). The flipped classroom can have some positive impact on learning outcomes, student motivation and interest, and overall success in STEM disciplines (Petrillo, 2016).

Perspectives of Active Learning in STEM Education

Since the late 1990s, science educators have been encouraged to implement active learning strategies to model the methods and mindsets that are at the core of scientific inquiry and to offer opportunities for students to connect abstract ideas to real world applications in order to gain skills and knowledge that persist beyond the course in which it was acquired (Allen & Tanner, 2005). Ross and Fulton (1994) conducted one of the earlier active learning studies in STEM education. This study was done over five years in a two course analytical chemistry sequence to assist students in becoming more effective learners in a non-competitive, cooperative learning environment. The researchers describe the process by which the two courses were restructured to incorporate cooperative learning techniques and the distribution of additional study materials to enhance the students' learning experiences in these courses.

The senior comprehensive exam results for all students who took the sequential course were compared for students who were enrolled in the active learning course versus those who were not and the students who were enrolled in the active learning course performed moderately better. When compared to the national norms at that time, the raw scores for 65% of the students who took the standard ACS Analytical Exam Form AN88 were at or above the national average and 20% of the scores were above the 90^{th} percentile; therefore it seems the students under the active learning instruction developed a solid background in analytical chemistry while still gaining the rigor necessary to compete nationally (Ross & Fulton, 1994). The researchers also reported that students thinking and problem-solving skills improved significantly as a result of their participation in this active learning course as demonstrated in the students' ability to listen, formulate questions and answers more carefully, and their ability to defend their answers. Another positive benefit of this implementation of active learning was the improvement in student attitudes toward learning, student development of effective and efficient learning strategies, and an increase in student motivation to excel.

Even with the documented success of some initial STEM active learning studies, sometimes it can be challenging for professors and students to adjust to a 'new' learning technique which is student centered and requires each student to be actively involved in the classroom activities, especially in very large class sizes. Allen and Tanner (2005) focused on active learning strategies that can be used with large class sizes. Specifically, they highlighted the following techniques: (i) beginning and ending the lecture with student discussion questions, (ii) using classroom technology for immediate feedback without requiring the professor to spend time grading, (iii) assigning student presentations and or projects, (iv) using learning cycle instructional models which involve the students at various phases of the learning experience through activities like reading, watching video clips, responding to thought-provoking questions, etc., (v) implementing peer-led team learning, (vi) modeling inquiry approaches, (vii) using problem-based learning and case studies, (viii) developing a workshop course which ties all of the classroom concepts and laboratory experiments together, and (ix) course redesigning or enhancement (Allen & Tanner, 2005). This study highlighted two major active learning strategies, cooperative learning and problem based learning, and also identified many other activities that support student engagement. Although these researchers focused on strategies that work well for large class sizes, all of these techniques can also be implemented effectively in smaller classes as active learning activities.

Along with being strategic about which activities are incorporated into the classroom, when constructing active learning courses it is critical to create a supportive and safe learning environment; set a positive tone in the classroom from day one. Smith, Clarke Douglas, & Cox (2009) presented the how people learn framework and the backward design approach are presented for designing courses that are thoughtfully constructed to optimize student learning. In the how people learn framework there are three components which intersect and are all a part of the learning community, which include learner centered, knowledge centered, and assessment centered instructional strategies. A learner centered atmosphere ties the interests, strengths, and preconceptions of learners to their current academic tasks and learning goals and assists students in identifying how they learn best. Therefore, it is important to check the academic backgrounds and academic majors of students prior to the first day of classes. A classroom setting that is knowledge centered is designed based on an analysis of student learning outcomes and helps students develop the fundamental knowledge, skills, and attitudes needed for successful transfer of this knowledge. An assessment centered environment means providing many opportunities to observe and make evident students' progress from what they currently understand to the ultimate learning goals in an effort to allow students to continue improving their weaknesses and revising their thinking. Providing the students in the class with some type of assessment or knowledge check each week gives the professor and students constant feedback about their progress in the course. Community centered means providing a supportive, enriched, and flexible learning environment inside and outside the classroom where all students can learn, feel comfortable asking questions, and work together (Smith et. al., 2009). All of these elements impact the overall success of STEM course implementation and student achievement academically and professionally. The backward design process requires the professor to do the following: (i) identify learning outcomes, (ii) determine what assessments will be used, and (iii) plan instruction with a focus on student engagement pedagogies (Smith et. al., 2009).

In summary, increasing the sense of community among STEM students and between students and professors within STEM classrooms is valuable, since cooperative learning researchers and practitioners have shown that positive peer relationships are important to overall college success. More supportive and engaging learning environments can help us accomplish our most important outcomes for STEM graduates: stronger critical thinking and reasoning skills, problem formulation and problem-solving skills, skills for working in a team, and confidence in developing solutions to practical problems (Smith et. al., 2009).

In a synthesis of research, Eison (2010) reported that active learning instructional strategies can be developed and implemented to engage students in creative or critical thinking, which can be done in pairs, groups, or as a whole class. This study highlighted some successful studies that have been done with large numbers of students in different types of STEM courses and the importance of students' engagement in their learning. It was also noted that active learning does not require technology and it can be done can during class time or outside of class time. In this study a combination of instructional strategies are highlighted and the differences between traditional lecture and interactive lecture are described.

According to Eison (2010), there are some challenges when implementing an active learning instructional methodology. For example: the professor may not be able to cover as much course content within the class time available, preparation for active learning activities may require more time, large class sizes may impede implementation of active learning strategies, a lack of materials or equipment needed to support active learning approaches, and students may resist non-lecture approaches (Eison, 2010). As a result, it is useful for the professor to begin with traditional instructional strategies and build up to including more student centered activities.

The lack of academic engagement in introductory STEM courses is considered to be a leading reason students change to non-STEM majors (Gasiewski et al., 2012). Recognizing the connection between student engagement and student performance, the physics faculty at a southern university adapted a model of active, collaborative, inquiry-based learning for their introductory calculus-based physics courses (Gatch, 2010). In the fall semester of 2006, the faculty piloted its first studio course; a course that seamlessly integrated the lecture and laboratory courses into one course with much of the class time devoted to student-centered learning. The number of studio courses increased each semester until the full implementation of studio courses in fall 2008. Assessments of student learning outcomes and surveys of student attitudes were conducted throughout the conversion from lecture and laboratory courses to the studio courses. The Force Concepts Inventory (FCI) and the Maryland Physics Expectations Survey (MPEX) were used for students enrolled in Physics I; and the Conceptual Survey in Electricity and Magnetism (CSEM) and the Colorado Learning Attitudes about Science Survey (CLASS) were used for students enrolled in Physics II. Results indicated that students completing the Physics I and Physics II studio courses had greater learning gains than students who took the traditional courses. The results from the MPEX showed positive shifts in the independence, math link, concepts, and reality link categories; negative shifts were seen in the coherence and effort categories. Similarly, the CLASS showed positive shifts in all categories that were measured for the Physics II students (Gatch, 2010).

The decision of the faculty to adapt the studio model with student-centered active learning strategies was supported by the results of the research. Although there was no disaggregation of the data to reveal any underlying trends in areas such as previous academic history or ethnicity, the restructuring of the introductory physics courses has created a format that allows for increased student engagement which is linked to student performance.

Another study, by Freeman et al. (2014) produced an extensive quantitative analysis of active learning research in college STEM courses. The researchers tracked and analyzed studies from and found that 642 of them met the criteria of: (i) contrasting traditional lecturing with any form of active learning, (ii) occurring in the context of regularly scheduled undergraduate courses, (iii) being limited to changes in how the classes were conducted, (iv) involving a course in astronomy, biology, chemistry, computer science, engineering, geology, mathematics, environmental science, food science, physics, psychology, or statistics, and (v) including data on student performance. Further analysis of these studies narrowed the research to 225 studies that had examination equivalence, student equivalence, instructor equivalence, and data that could be used for computing effect size (Freeman et al., 2014). A meta-analysis of those 225 studies gave a result consistent to the results of less rigorous studies – active learning strategies achieve measurably better student performance outcomes. The research showed that students in classes taught by traditional lecture were 1.5 times more likely to fail than students taught in active learning classrooms. When analyzing the data collected and examining the type of course and the level of course offered, there was statistically no significant difference in how active learning impacted students in any of the courses (Freeman et al., 2104).

The active learning approach produced the same positive effect in all of the courses throughout all STEM disciplines. Active learning is a broad term that incorporates many techniques. Although the study has important implications for college level STEM education, it does not confer a type of active learning as being more beneficial to student performance than another. An implication of the study for further research in college level STEM education is the comparison of the impacts of different active learning strategies on student performance. Further research could be expanded to include findings of the impact of active learning on underrepresented minorities who do not complete undergraduate STEM degrees at the same rate as their counterparts.

As student centered learning strategies become a mainstay in STEM education reform, problem based learning helps to prepare students to deal with the complex problems they will encounter in the real world. This learning strategy is well suited for engineering education because functioning as an effective member of a team to solve complex problems that are not well structured is what engineers do in practice. In an investigation of PBL in an undergraduate electrical engineering course in a large mid-western university, Yadav, Subedi, Lundeberg, & Bunting (2011) used traditional lecture as the baseline phase and PBL as the experimental phase to compare the learning gains of students from PBL and traditional lecture. Instructor-developed pre-tests and post-tests assessed knowledge and conceptual understanding. The study showed that learning gains from PBL were almost twice as high as learning gains from traditional lecture (Yadav et al., 2011). This technique worked best in advanced courses with students who have already acquired strong fundamental skills. This study adds to the body of empirical data to support PBL as an effective instructional strategy, but more research needs to be done in this area.

Another study was conducted at a large research university in an introductory biology course with a high number of students in order to make time for in class cooperative learning activities which focused on critical thinking (Prunuske et al, 2012). There were 130 students selected through a competitive application process for enrollment in this course and they were informed before the first day of class about way the course would be conducted. The researchers in this study assigned a series of short online lecture notes for students to read prior to the class meeting where the topic would be covered so that in class time could be used to focus on doing examples and checking student knowledge. In addition, clickers were used during class time to assess student knowledge.

This study showed based on student survey and performance on basic level questions advantages in utilizing these active learning techniques. There are some benefits to curricular redesign that integrates in-class cooperative learning activities and technology, like online lectures and the use of clickers in class (Prunuske et al, 2012). This particular institution has a small percentage of minority students, which is a limitation of this study.

In an inquiry-based learning study, Kogan and Laursen (2014) reported modest change when comparing grades in subsequent classes of students who took IBL college mathematics courses to the grades of students who took non-IBL courses. In a large scaled mixed methods study involving four universities with IBL Math Centers, the researchers used students' academic records, observations, interviews, surveys, and test data to assess the long-term effects of IBL in college mathematics courses. From the observation study, the researchers found that the students in the IBL courses asked more questions and took on more leadership roles in the classroom. In the IBL courses, 60% of class time was spent on student-centered activities; whereas in the non-IBL courses, over 85% of class time was spent on professor lecture. Courses were chosen because they had an adequate amount of students enrolled in both IBL sections and non-IBL sections, their placement was early in the course sequence, and they were taken early enough to have subsequent courses taken at the time of the study (Kogan & Laursen, 2014).

When disaggregating the results by prior achievement, this study showed that the performance of low-achieving students improved after taking IBL courses when compared to their own prior achievement and to the achievement of students who did not take IBL courses. When disaggregating for gender, the study revealed that the impact of having taken IBL courses was mainly effective for women. Women taking non-IBL courses had a similar success to men, but reported lower confidence at the end of the course. The study further showed that even though less material was covered in IBL courses due to the time given to student-centered activities there was no adverse impact on the students' performance in subsequent classes. It provided evidence that IBL strategies can have lasting effects on groups of students whose prior mathematics achievement may have been low. Thus, this study supports the premise that active learning can improve student outcomes.

As the popularity of the flipped classroom learning strategy has increased, studies have been done to determine the impact of this technique on student achievement. Sahin, Cavlazoglu, and Zeytuncu (2014) sought to answer these questions in a study of 96 students in a college calculus class in the spring 2013 semester at a college in Texas. In this class, three subjects were taught using the flipped classroom method and seven subjects were taught using traditional lecture method.

They found that quiz scores of the students were significantly higher for the subjects taught using the flipped classroom method than for the traditionally taught subjects (Sahin et al., 2014). Through survey, they also found that the majority of the students felt that the flipped classroom strategy helped them to perform better. The results of this study align with the results of similar studies on the flipped classroom learning strategy.

In a subsequent study on the flipped classroom, Petrillo (2016) examined the effectiveness of the flipped classroom on student grades in the class and student attitudes/perceptions about their experiences in a flipped or inverted style class. This study was conducted at a small, comprehensive, American university that has a school of engineering to determine if the flipped classroom concept would improve student success rates in first semester college calculus in response to the high failure rate of students in the course.

A comparison of the success rates for the lecture (fall 2005-spring 2009), lecture with activities (fall 2009-spring 2012), and flipped classroom (fall 2012-fall 2014) models was done. The flipped classroom model showed the highest success rate at 69.5%; followed by lecture with activities at 64%; and lecture at 57.4%. In addition, student surveys were used to gain insight into students' opinions about the course content and the instructional strategies. Due to their success with the flipped classroom implementation, Petrillo (2016) indicated that this method has been adopted as a standard American Chemical Society (ACS) for Calculus I and a comparable course for Calculus II is in the developmental stage.

Cronhjort, Filipsson, and Weurlander (2017) conducted a study in which certain sections of a class were taught using the traditional lecture method and other sections of the course were taught using a flipped classroom technique yet all student participants were administered the same Calculus Baseline Test which included 15 multiple choice questions divided into three categories: pre-calculus, calculus concepts, and calculus theory and formalism. This test was given as a pre-test in the beginning of the semester and as a post-test at the end of the course prior to the final exam. In addition, student participants were given final examinations and student engagement surveys.

The findings of this study indicated that the flipped classroom benefited students learning and overall experience in the classroom. The failure rate decreased more and the highest grade increased more in the flipped classroom compared to the lecture class. This indicates that the flipped classroom benefited low and high-performing students (Cronhjort et al., 2017). Similarly, Petrillo (2016) found that the failure rate decreased when the flipped classroom technique was implemented in the calculus course.

Based on the survey results in Cronhjort et al. (2017), students enrolled in the flipped classrooms felt more engaged and believed that they were a part of a learning community in which they were fully involved and contributed to the learning experience, instead of feeling like isolated independent learners. One setback of the flipped classroom is that students with special needs can find certain aspects of the classroom setting challenging (Cronhjort et al., 2017).

This study can be augmented by implementing different types of active learning strategies and creating experiences that facilitate thinking, questioning, application, and peer interactions. In an effort to determine if the flipped classroom approach had a greater impact on student performance than traditional and online approaches in a C# programming course, Sharp and Sharp (2017) conducted a quantitative research study. The study comprised eight semesters from fall 2012 to spring 2016 and 271 participants enrolled in an introductory C# programming course.

The data collected each semester were lab assignment scores, exam scores, final exam scores, and overall course averages. The data analyses revealed that student learning increased with the flipped instructional approach when compared to the traditional approach and that additional research must be done to compare student academic performance between online approaches and the flipped classroom approach (Sharp & Sharp, 2017).

The study was limited by the number of participants in each method. Of the 271 participants, 136 were in traditional sections, 96 were in online sections, and 39 were in flipped sections. The results of this study could be strengthened with more students in the flipped sections. This study does, however, extend the body of work that supports student-centered learning approaches such as the flipped classroom model.

What follows is Table 1, which summarizes the active learning perspectives in college level STEM education that were presented in this paper. The type of institution, type of course, techniques implemented, and the findings are outlined in Table 1. For the sample size, N represents the total number of students participating in the study and n represents the number of students participating in the active learning components. Overall, the results of the research showed that active learning techniques enhanced student performance and increased learning gains.

Discussion

This paper reviewed analyses of active learning approaches in college level STEM courses. Throughout our review, we have shown that there is a relationship between student engagement and student learning. Based on the studies reviewed, student engagement in the learning process enhances student academic performance, increases student interest and motivation, and better equips students with the ability to apply the knowledge and skills gained in their STEM courses to real-life problems.

Table 1. Active Learning Studies in Undergraduate STEM Education

Researchers	Sample	Course	Technique	Findings
Ross and Fulton (1994)	students at a private liberal arts college *(N=65, n=39)*	analytical chemistry two course sequence	cooperative learning	Students in active learning courses performed better than students who were not.
Gatch (2010)	students at a large research university	Physics I, Physics II	inquiry-based learning studio courses	Learning gains were greater in studio courses than in traditional lecture and lab courses.
Yadav, Subedi, Lundeberg, and Bunting (2011)	students at a large mid-western university *(N=55, n=55)*	electrical engineering course	problem-based learning	Learning gains from PBL were almost twice as high as learning gains from traditional lecture.
Prunuske, Batzli, Howell, and Miller (2012)	students at a large research university *(N=130, n=130)*	introductory biology course	cooperative learning and online lecture	Students performed better on lower-order cognitive skills questions.
Kogan and Laursen (2014)	students at two universities hosting IBL Math Centers *(N=2447, n=383)*	various mathematics courses	inquiry-based learning	Low achieving students improved after taking IBL courses.
Sahin, Cavlazoglu, and Zeytuncu (2014)	students at a college a university in the south *(N=96, n=96)*	Calculus	flipped classroom	Scores were significantly higher for students taught using the flipped classroom method.
Petrillo (2016)	students at a small comprehensive university *(N=530, n=473)*	Calculus	flipped classroom	The flipped classroom model showed the highest success rate.
Cronhjort, Filipsson, and Weurlander (2017)		Calculus	flipped classroom	The failure rate decreased and the highest grade increased.
Sharp and Sharp (2017)	*(N=271, n=39)*	introductory C# programming course	flipped classroom	Student learning increased with the flipped classroom approach.

However, there can also be some challenges associated with adjusting the method of instruction to include active learning. These challenges are related to the professor modifying the way they teach and student reception of and preparedness for a classroom setting with less traditional teaching strategies. Some of these challenges include the following: (i) inability to cover all of the required material, (ii) the amount of time a professor may need to spend on preparing the modified instruction, (iii) ensuring that the adjustments match well with the professor's personality and the student population in the respective class, and (iv) lack of equipment or resources to make the desired change. Therefore, it is critical for the professors to determine based on their institution and the institution's student population what modifications can be made and include them gradually, if necessary, to avoid some of the potential challenges.

There are a variety of ways to incorporate active learning strategies into college level STEM courses. Some strategies are designed to encourage each student to express his/her attitudes and values towards the subject matter and others are designed to increase retention of the material presented in the class. With the goal of increasing student academic performance, what follows are three examples of activities that can be used to enhance student engagement (California State University). A reading quiz can be used to check student comprehension of the assigned readings to help the students identify how to perceive the most important parts of what they read. Student summary of another student's answer can be used to promote active listening. After a student answers a question, another student can be asked to summarize the first student's response. Concept mapping can be used to help students identify the connections that exist between terms or concepts covered in the course material. This method usually assists students with thinking deeper about the concepts and understanding the material at a higher level.

Technology is another valuable tool that can be used to complement active learning teaching strategies. Depending on the type of technology utilized, it can be used during class time or outside of class time.

Many professors are using online learning components, which have been shown to improve student academic performance (Prunuske, 2012). Online videos, clickers, or online platforms for discussions/posts/homework are all examples of ways technology can be incorporated into college level STEM courses.

Learning is active, personal, and intentional, not a passive process (Ross & Fulton, 1994). Studies indicate that active learning has been effective in engaging students in the learning process. Moreover, students actively engaged in their own learning experience increased learning gains and enhanced retention of course material; therefore, they are more likely to persist in STEM majors.

Suggestions for Future Research and Practice

The United States has developed as a global leader, in part due to the intelligence and efforts of scientists, technologists, engineers, and mathematicians. To ensure our nation's continued scientific and technological growth and advancement, supporting undergraduate student success in science, technology, engineering, and mathematics disciplines is paramount (Espinosa, 2011). Currently, there are not enough people from diverse populations, including women, participating in the STEM academic and professional communities. Therefore, to remain as a competitive nation in STEM, it is critical to create learning opportunities and pathways for all students, including those from groups traditionally underrepresented in STEM, who are interested and capable of pursuing education and careers in these fields. The need to broaden participation in STEM is especially important for those who identify as African American or Black (Upton and Tanenbaum, 2014). In that regard, Historically Black Colleges and Universities may have a unique advantage in the nation's efforts to significantly increase the participation of this population (Upton, 2014). To support this effort, improved STEM pedagogical practices, like active learning techniques, have been on the horizon for years. Recently, these methods have gained increased significance given the desire of educators to increase the numbers of women and minority students in STEM with the overall goal of using innovative teaching strategies to benefit all students (Espinosa, 2011).

The value of the diversity of students is recognized when active learning is implemented in STEM courses (Prunuske et al., 2012). As the body of worked on active learning strategies in undergraduate STEM education expands, future research should focus on the impact of innovative teaching strategies on underrepresented groups. It is important for professors at all types of institutions to search for new ways to engage all students and enhance the learning environment since the dynamic between faculty and students in STEM courses impacts the students overall learning experience. If professors engage students from diverse backgrounds, they are more likely to excel and persist in STEM majors.

There are several open questions related to the impact of active learning teaching techniques in college level STEM education. Future research in undergraduate STEM education should include the following: how to optimize the use of technology in STEM courses, how to integrate course content across STEM disciplines, how active learning in a prerequisite course effects performance in subsequent courses, and how active learning impacts student graduation rates in STEM majors. Increasing the girth of knowledge on best practices in college level STEM education will lead to the United States maintaining its position as a leader in science, technology, engineering, and mathematics.

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STEM Professional Development Policies in the United States: Trends and Issues

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Introduction

In this chapter, an overview of policies regarding professional development for science, technology, engineering and mathematics (STEM) education in the United States, as well as associated trends and issues, are presented and discussed. The historical outcomes of the education system in the United States has altered legislation which has, in turn, impacted specific subjects and professional development. The progression of education and the pieces of legislative policies that advanced education in the United States have shed light on the creation of professional development for STEM.

Professional Development Policies

In order to understand STEM education, one cannot overlook professional development policies' historical context. Education in the United States progressed slowly until the mid to late 1800s. As the United States entered its industrial revolution period (1860-1890), the role of schooling in society, in terms of curriculum and methodology, changed (Del Giorno, 1967). The Nation's welfare depended on the proper education of its citizens; this created great concern for the future (Mackenzie, 1894). Concerns for the Nation's education prompted the leading educational organization, National Education Association, to form the Committee of Ten in 1892. The Committee of Ten appointed conference committees for nine subjects: 1. Latin; 2. Greek; 3. English; 4. Other Modern Languages; 5. Mathematics; 6. Physics, Astronomy and Chemistry; 7. Natural History (included Biology, botany, zoology, and physiology); 8. History, Civil Government and Political Economy; and 9. Geography (National Education Association, 1894).

Organizing the subjects resulted in an increase in students taking science courses, as well as the inclusion of labs for science whenever possible. Likewise, it gave rise to the formation of a curriculum structure with defined subjects (Del Giorno, 1967).The Committee of Ten also established the introduction of certain subjects early on in a child's education, and the provisions for instruction in all subjects for both college-bound and non-college-bound students (National Education Association, 1894, 1918;

Weidner, 2004). These changes created opportunities and a need for teachers to receive professional development.

In the latter part of the 19th century, professional development became a great concern with the emergence of textbooks that questioned teaching methodology. These textbooks addressed specific teaching methods, such as not using the textbook alone, and allowing the student to discover things on his or her own (Del Giorno, 1967). During this time, teachers received professional development by reading magazines (such as *Science)*, books, and letters (like the *Preston Papers*), field experience, and/or trainings (such as those the Industrial Education Association offered to manual arts instructors). This created unstructured professional development, or professional development that occurred without financial assistance from the federal government.

To describe professional development, one must combine several definitions: First, professional development is a teacher's ongoing learning experience (Luft & Hewson, 2014). Christopher Day's (1999) definition of professional development includes all-natural learning experiences and planned activities intended to provide a direct or indirect benefit to the individual or school. Through these activities, teachers "renew and extend their commitment as change agents" (Day, 1999, p. 18). Summarizing these definitions, one could operationally define professional development as a continuous learning experience that has a direct and indirect impact on the teacher and the teacher's commitment as a change agent in his or her classroom.

There are implications for this definition in legislations at the state and federal levels. At the state level, for example, in Milwaukee, WI, 1893, Dr. Lorenzo Dow Harvey organized classes for teachers and principals. They were to meet every other Saturday to "stimulate teachers' professional reading and thought on the application of psychological principles to the everyday situations of the schoolroom" (Bawden, 1950, p. 90). At the federal level, professional development is first addressed informally in the Morrill Act of 1862, and first addressed formally (funds allotted for professional development) in the 1978 amendments of Elementary and Secondary Education Act.

One must view the history of professional development -- whether for science, technology, engineering, mathematics, or other subjects -- through the lens of educational policy, curriculum, and tools for education. Taking this approach makes it easier for one to see professional development's transition from unstructured (which still takes place today) to structured (mandated by federal and state policies).

A Brief Overview of STEM Professional Development Policies Past

From the mid 1800s to the early 1950s, science, technology, engineering, and mathematics education took slightly different paths. This led the federal government to pass legislation that directly impacted each subject differently. Teachers received professional development for each subject in the 1800s and early 1900s mainly through journal articles and books. By the mid 1900s, professional development for science, technology, engineering, and mathematics educators had expanded to include preparatory courses and some formally structured programs (Del Giorno, 1967; Hurd, 1961). As the nation entered the 1950s, the federal government had enriched itself with science, technology, engineering, and mathematics education policy. Educational policies from this point forward included rhetoric related specifically to these subjects.

Much of the federal education policy in the 1990s and 2000s concentrated on standards, assessment, and accountability (Hurst, Tan, Meek, & Sellers, 2003). States were under federal mandates to create standards and assessments that required teachers to be trained and educated on updates for each state's educational directives. States had to review and revamp many of the professional development programs that already existed to accommodate these federal mandates. Moving into the 2000s, the federal government embedded itself further into science, technology, engineering, and mathematics education, as well as teacher professional development, with a major educational reform act: No Child Left Behind.

STEM Education Professional Development Policies Present

The chief educational policies passed from 1950 to 1999 facilitated the transition of professional development from solely unstructured, to both unstructured and structured, providing trainings for science, technology, engineering, and mathematics teachers. The policies also offered much support and funding for the development of curriculum for K-12 science and mathematics. Engineering and technology K-12 curriculum did not receive as many provisions as mathematics and science, but would eventually receive attention in the 2000s. Along with funding and support came mandates on the programs for research, placing science, technology, engineering, and mathematics education and its professional development under much scrutiny. STEM – a buzzword/term used in reference to science, technology, engineering, and mathematics, and professional development and education related to these subjects -- began to emerge among policy writers and education professionals.

The National Science Foundation coined STEM (science, technology, engineering, and mathematics) some time in the early 1990s (Dugger, 2016a). Even though the acronym included engineering and technology, when used, it most often referred to mathematics and science. This could be because past federal policy stated that science included engineering and technology; in many instances, engineering and technology were described as tools used in education, rather than subjects in their own right. It was not until 2010 that the term, STEM appeared in a federal policy and was defined as “the academic and professional disciplines of science, technology, engineering, and mathematics” (America COMPETES Reauthorization Act, 2011, §2). Just like the unclear use of the acronym, STEM, the realm of professional development was murky. In turn, it received criticism.

Progress Through the Teacher Pipeline: 1992–93 College Graduates and Elementary/ Secondary School Teaching as of 1997 acknowledged research that indicated K-12 teacher professional development was “viewed as inadequate by many scholars and policymakers, and initiatives to improve [were abundant]” (Henke, Chen, & Geis, 2000, p. 2). A core argument was that formal professional development would not have lasting effects unless it was connected to the classroom (Fullen, 1991). The National Center for Education Statistics (2001) found that only 18 percent of public school teachers felt that professional development was connected to other programs at their schools.

It was also suggested that teachers were more likely to participate in professional development that focused on state or district curriculum and performance standards (80 percent), while 74 percent preferred integration of educational technology trainings, and 72 percent preferred an “in-depth study of the subject area of the main teaching assignment” (Parsad, Lewis, Farris, & Westat, 2001, p. 4). A study for mathematics and science education indicated that instruction around use of technology in the classroom was teachers’ most highly perceived need within professional development. Content knowledge was teachers’ second most highly perceived need (mathematics and science content for elementary teachers and science content only for middle school teachers; high school teachers were not concerned with content knowledge) (Weiss, Banilower, McMahon, & Smith, 2001). The findings in these studies, as well as with several others, prompted policy writers to include provisions for professional development in the rewrite of the Elementary and Secondary Education Act, No Child Left Behind.

The No Child Left Behind Act of 2001 (NCLB) included not only improvements for professional development and stipulations for stronger accountability, but also initiatives to help revitalize STEM education (United States Department of Education, 2012). The NCLB allowed funds to be combined from Title II of this Act (“preparing, training, and recruiting high quality teachers and principals”), other Acts, and other sources for professional development (No Child Left Behind, 2002, §1119).

It also specified that there should be a

> “(2) focus on the education of mathematics and science teachers… [that development] continuously stimulate teachers’ intellectual growth and upgrade teachers’ knowledge and skills… (3) bring mathematics and science teachers… together with scientists, mathematicians, and engineers to increase the subject matter knowledge of mathematics and science teachers… (5) [and] improve and

> expand training of mathematics and science teachers… in effective integration of technology (§2201)."

The NCLB focused strongly on professional development in science and mathematics. Engineering was encompassed in science, and technology education was viewed as it had been in previous educational policies: a tool to enhance education.

The focus on professional development within mathematics and science education was further established in NCLB through provisions to grow partnerships with mathematics and science educational agencies outside of the classroom.

The Mathematics and Science Partnerships (MSPs) had a goal to improve students' academic achievement in mathematics and science through quality instruction. The MSPs' purpose was to encourage higher institutes to improve teacher education for mathematics and science teachers by "focus[ing] on the education of mathematics and science teachers as a career-long process that continuously stimulates teachers' intellectual growth and upgrades teachers' knowledge and skills" (No Child Left Behind, 2002, §2201). The MSPs were to bring together educators and other professionals in mathematics and sciences to improve teaching skills by exposing teachers to sophisticated laboratory equipment and other resources. The creators of MSPs hoped that teachers would be able to develop curriculum that aligned with the state's standards, and that teachers would enforce the "standards expected for postsecondary study in engineering, mathematics, and science" in classrooms (No Child Left Behind, 2002, §2201). To fulfill NCLB requirements, states were mandated to create assessments and curriculum that aligned with standards. The assessments would show the long-term trend in reading and mathematics for students, and create an avenue for improving professional development.

By 2004, all states had professional development requirements for license renewal that varied in criteria from superintendent recommendations to 150 hours of professional development (Cavell, Blank, Toye, & Williams, 2004). 37 states had funds specifically for professional development programs, 24 states established policies that aligned professional development with state content standards, and 35 had standards in place for professional development (Cavell, Blank, Toye, & Williams, 2004; Skinner, 2005).

States' initiatives for professional development created an increase in teacher participation, but "most teachers' professional development experiences were not of high quality" (National Science Board, 2006, p. 1-41). In 2007, Rising Above the Gathering Storm stated that teachers were the key to improving student performance, which influenced the government to place a stronger emphasis on STEM education in the next federal policy.

In Rising Above the Gathering Storm (2007), a committee formed by the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, voiced their concerns on the erosion of the scientific and technological building blocks that were needed to maintain the United States' economic leadership. The report identified two key challenges connected to STEM skills: the creation of high-quality jobs for Americans, and the nation's need for affordable, clean, and reliable energy. The committee recommended four actions to focus on helping the country to overcome these challenges; one of the actions called for changes in K-12 education. This action step was referred to as 10,000 Teachers, 10 Million Minds and would recruit 10,000 science and mathematics teachers annually, educating 10 million minds. Rising Above the Gathering Storm (2007) acknowledged the teacher shortage. Likewise, it acknowledged that students had only a 40 percent chance of having a teacher for chemistry who had majored in the subject. If the subject were English, however, that possibility rose to 80 percent (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007). Rising Above the Gathering Storm (2007) specified a need for professional development opportunities that were high-quality, focused on content, had a significant effect on student performance, included year-long mentoring, contained pedagogical strategies, and provided high-quality curricular materials. To tackle the goal of 10,000 Teachers, 10 Million Minds, federal policymakers drafted a bill to provide resources for the enhancement of STEM education and professional development.

The America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act of 2007, or America COMPETES Act, was "an Act to invest in innovation through research and development, and to improve the competitiveness of the United States" (intro.). The America COMPETES Act Title VI was devoted to education, and allotted grants for teachers to earn master's degrees in science, technology, engineering, and mathematics education. The America COMPETES Act authorized programs for teachers to experience research, and created other professional development opportunities to enhance teachers' science, technology, engineering, and mathematics content knowledge. The "National Panel on Promising Practices in K-12 STEM Teaching and Learning" was tasked with "identifying promising practices for improving teaching and student achievement in science, technology, engineering, and mathematics" (§6131).

Technology and engineering, for what seemed like the first time in a federal educational policy, were treated as separate subjects, and the acronym, STEM was used. It was not until the Act was reauthorized in 2010 as the America COMPETES Reauthorization Act that STEM was defined. In December 2007, America's economy began to show signs of instability. The federal government signed the American Recovery and Reinvestment Act of 2009 (ARRA) to avert education cuts (United States Department of Education,2009a).

The ARRA allotted $4.35 billion in funds for a competitive grant program called *Race to the Top*. A criterion on the application required states to include a plan for high-quality professional development, and the government gave priority to STEM-focused applications (United States Department of Education, 2009b). The monetary investments from ARRA and *Race to the Top* provided education the means to continue to move forward. According to the Nation's Report Card 1990-2007 and the Trends in International Mathematics and Science Study or TIMSS 1995 and 2007 reports, overall, the nation was making progress. In 2010, the America COMPETES Act was reauthorized to continue the growth of STEM education.

In America COMPETES Reauthorization Act, there were many provisions for improvement in education and professional development for science, technology, engineering, and mathematics. The Office of Science and Technology Policy established a committee – CoSTEM -- to coordinate Federal STEM education and STEM programs (§101). CoSTEM was tasked with creating a five-year strategic plan that pledged money for recruiting high-quality STEM teachers, producing high-quality professional development, strengthening the infrastructure for supporting STEM instruction and engagement, and providing STEM resources and equipment (National Science and Technology Council Committee on STEM Education, 2011). In America COMPETES Reauthorization Act, each letter in the acronym, STEM was used liberally throughout the policy as an abbreviation for its associated subject -- not to describe an integration of the subjects.

The America COMPETES Reauthorization Act of 2010 brought about more changes to STEM education. A section entitled *Science, Technology, Engineering, and Mathematics Support Programs*, which housed the National Science Foundation Authorization Act of 2010, reflected many advances. This act made available $9.3785 billion to be used for education and human resources at the National Science Foundation (§503).

This allotment of funds to the National Science Foundation (NSF) was important to STEM education because in 2012, an analysis of federal funds suggested that the majority of STEM education funding and professional development came from the NSF. This analysis stated that the NSF was a "key component of the federal STEM education effort" (Gonzalez, 2012, p. 1).

A 2010 report by the Committee on Standards for K–12 Engineering Education emphasized the lack of attention that the "T" and "E" in STEM had historically received. The America COMPETES Act of 2007 and America COMPETES Reauthorization Act of 2010 seemed to be the first federal education policies to pull technology and engineering out from under the umbrella of science. Though it was not very clear in the policies, the "T" in STEM was addressed in education as a tool to help improve or enhance the curriculum of other subjects.

For technology education to take a stand among the major subjects, a clear definition – in addition to standards – was necessary. The first standards written for technology education were the 2000 *Standards for Technological Literacy: Content for the Study of Technology* (2000/2002/2007). Within these standards, technology and technology education were defined.

> "Technology is the innovation, change, or modification of the natural world or environment to satisfy perceived human wants and needs…Technology education is [further] a study of technology, which provides an opportunity for students to learn about the process and knowledge related to technology that are needed to solve problems and extend human capabilities" (International Technology Education Association, 2007, p. 242).

Having a clear definition of technology, technology education, and standards provided the "T" in STEM with the foundation to become its own entity during the 2015 Elementary and Secondary Education rewrite debates.

In the same 2010 report, The Committee on Standards for K-12 Engineering Education provided several reasons as to why engineering had yet to create K-12 standards. The Committee stated that engineering education was strongly connected to science, mathematics, and technology. The standards for engineering education were the same as the standards for these subjects. Thus, engineering education did not need its own. Another rationale was that K-12 engineering was still in its infancy, making it difficult for engineering education to stand on its own (Committee on Standards for K–12 Engineering Education, 2010). However, engineering education was not without some guidelines. The Accreditation Board for Engineering and Technology (ABET) adopted Engineering Criteria (EC) 2000 in 1996.

The criteria that EC2000 and later amendments set were directed toward post-secondary education programs. This did not prevent K-12 educators from using the EC2000's criteria to create curriculum for the "E" in STEM. From 2010 to 2015, STEM education and professional development for each of these content areas experienced growth. The federal government's focused on creating integrated curriculum for STEM, and on recruiting highly qualified STEM teachers.

In order to practice the integration of STEM, educators fashioned curriculum by using the standards that the "National Council of Teachers of Mathematics' *Principles and Standards for School Mathematics* (2000) , the National Research Council's *National Science Education Standards* (1996) , *Standards for Technological Literacy* (2000), the Accreditation Board for Engineering and Technology's *Engineering Criteria 2000* (1997), and the *Common Core State Standards Initiative for Mathematics* (2011)" (Asunda, 2012, p. par. 18) had set forth.

The government debated STEM-specific standards, but had not yet set federal mandates. Though still on rocky ground, curriculum for STEM education was advancing. Teachers for STEM education, on the other hand, were in short supply, and many teachers were expected to retire over the next several years. These issues prompted the White House to run a campaign to recruit more STEM educators.

In 2011, President Obama set out to obtain 100,000 well-qualified mathematics and science teachers in ten years. The *100Kin10* was launched through the efforts of the Carnegie Corporation of New York and Opportunity Equation, to meet the President's goal. The *100Kin10*'s objective was to help train and retain STEM teachers by bringing together various sectors (i.e. federal, corporate, universities, and nonprofits). By August 2013, *100Kin10* had raised over $53 million, and was committed to training 40,000 teachers by 2016 (National Science Board, 2014). The debate over criteria and plans for reaching the President's goal and stalling ESEA's reauthorization made it necessary for President Obama to provide waivers for stipulations in the No Child Left Behind Act.

The NCLB included a deadline: all students needed to be proficient in math and reading by 2014. The waiver provided states with the flexibility to create their own plans for failing schools, as well as student-achievement goals (McNeil & Klein, 2011). The requirements for states to utilize the waiver included the creation of standards that focused on college and career readiness, and the development of teacher evaluations based on students' performance. The exchange over the flexibility of NCLB's mandates caused a shift in the theme of teacher professional development, from primarily content-focused to standards-based instruction emphasis. The National Survey of Science and Mathematics Education (2012) reported that 64 percent of science and 76 percent of mathematics teachers had participated in professional development directed toward states' science and mathematics standards (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013).

These findings countered those in 2000, when most science and mathematics teachers indicated that professional development was content-focused (Weiss, Banilower, McMahon, & Smith, 2001).

In 2015, after much debate and many amendments, the Elementary and Secondary Education Act was reauthorized as Every Student Succeeds Act (ESSA). The Nation's commitment to equal opportunity for all students was renewed. The ESSA included STEM education and professional development, but not to the extent proposed in the first drafts. It required the integration of engineering design skills and practices into the states' science assessments (§1201). In addition, states were expected to carry out programs that provided alternative routes for state certification, "especially for teachers of... science, technology, engineering, mathematics" (§2101).

The ESSA made states and local agencies responsible for developing and providing professional development for teachers to promote high-quality instruction in science, technology, engineer, ing, mathematics, and computer science (§2101, §2103). The ESSA allotted grants for STEM partnerships, which would replace the MSPs that were no longer receiving funding, and mandated that teachers with professional development instruction regarding the use of technology to enhance student achievement in STEM areas, including computer science (§4109). The ESSA used the acronym STEM to refer to science, technology, engineering, and mathematics which under the section, "well-rounded educational opportunities." The ESSA provided local education agencies with funds to create opportunities such as programs and activities for STEM (§4107). The ESSA contained a section for "STEM Master Teacher Corps," which were "State-led effort[s] to elevate the status of the science, technology, engineering, and mathematics teaching profession" (§2245). Another use of the acronym described what a "STEM-focused Specialty School" was:

> "a school, or dedicated program within a school that engages students in rigorous, relevant, and integrated learning experiences focused on science, technology, engineering, and mathematics, including computer science, which include authentic schoolwide research" (§4102).

The ESSA used the term, "integration" in conjunction with STEM, though it provided no further clarification on what this integration should have been for curriculum or standards development. Under the current federal educational policy – ESSA -- each subject (science, technology, engineering, and mathematics) has been addressed in some fashion. The policy still favors science and mathematics education, but it also tackles technology and engineering. In ESSA, the integration of STEM emerges, and professional development for STEM teachers is created or enhanced to include integration.

Discussion

The following discussion will identify any trends and issues in STEM education professional development policies

Trends

Based on the information stated above, it is obvious that professional development in STEM subjects (science, technology, engineering and mathematics) has varied widely in the past, but is progressing in similar ways in the present. In the past, professional development for STEM lacked structure, policy, and adequate curriculum materials and other resources. The emphasis on individual subjects such as science, technology, engineering and mathematics was high, and there was competition among these subjects for prominence and attention. This inspired individuals, groups, and organizations to create, offer, and participate in professional development depending on the STEM subject.

At the beginning of the twenty-first century, legislation impacted educational programs for students, as well as professional development workshops that science, technology, engineering, and mathematics teachers attended. The federal government passed several policies that had major ramifications for these subjects' curriculum, standards, and professional development. The "T" and "E" in STEM began to assert themselves and create their own identities, separate from mathematics and science.

The NCLB was a comprehensive bill that brought accountability to education and stressed the need for interactions between America's STEM businesses and STEM education. The America COMPETES Act placed heavy emphasis on STEM education and teacher recruitment for these subjects. Both the America COMPETES Act and the America COMPETES Reauthorization Act stipulated provisions to strengthen teaching and learning in the primary and secondary levels of STEM education. Both policies provided funding to the National Science Foundation for professional growth trainings, program and curriculum development, and standards geared toward the integration of science, technology, engineering, and mathematics.

President Obama's goal of 100,000 teachers for STEM is well on its way to being achieved. The 100Kin10 program has trained more than 40,000 STEM teachers, and has received tens of thousands of dollars to improve teachers' skills and provide support to help keep STEM educators in the classroom longer (100Kin10, 2016).

The ESSA has delivered a foundation for STEM education and its integration. The "T" in STEM has become stronger. Technology is an elective area in most states; over 28,000 men and women teach it (Dugger, 2016b). Technology education is now well-defined; and standards for the subject are in place.

The "E" in STEM is slowly progressing; some promising things are developing in the field. In Framework for Quality K-12 Engineering Education (2014) authors Moore, Glancy, Tank, Kersten, Smith, and Stohlmann proposed a clear definition for K-12 engineering education programs. These advances will help guide policy makers and educators in the creation of curriculum and standards for engineering, and in the integration of engineering in STEM (Moore, Glancy, Tank, Kersten, Smith, & Stohlmann, 2014).

STEM no longer places emphasis on science and/or mathematics alone. Each content area in the acronym is now addressed individually. In addition, the National Engineering Council and the National Research Council of the National Academies considers the integration of these subjects vital to the success of the nation's sustainability in innovation and foundation for successful employment. Even though the most recent federal educational policy – ESSA -- did not define STEM in terms of curriculum and standard-integration, it did contain provisions to form STEM-based programs and professional development models. STEM education continues to advance, and STEM educators will receive the training and support they need to help nurture the nation's aspiring scientists, technologists, engineers, and mathematicians: the future "STEMists."

Issues

As noted earlier, there is an expectation that teachers develop curriculum that aligns with standards and complies with NCLB's requirements. The NCLB's increased accountability mandates to states to create assessments in reading and mathematics opened up opportunities for professional development through Math Science Partnerships (No Child Left Behind, 2002). However, as Trivedi (2014) pointed out, a lack of adequate accountability measures continues to haunt professional development in STEM education. Considering the integrated nature of a set of distinct disciplines, establishing a set of unified assessments is not an easy task. Additionally, gender and socioeconomic achievement gaps, accessibility gaps, and poor teacher quality continue to add more challenges to STEM professional development.

Massimo (2015) and Hademenos (2017) observed similar issues, and suggested strategies -- such as revising structured, traditional, compartmentalized curriculum into integrated STEM curriculum, and developing suitable STEM teaching methods, as well as motivational learning activities and assessments – to overcoming these challenges. In context, teacher expertise is crucial. Considering the present state of the teaching force in science, technology, engineering and mathematics -- the limited teacher expertise and experience, especially in the elementary grades -- it is difficult for teachers to fully integrate these disciples into successful STEM lessons. On the other hand, forcing teachers at the secondary level with well-structured, discipline-based expertise to accommodate other disciplines in the name of STEM education is not without issues. As a case in point Kumar, Thomas, Morris, Tobias, Baker and Jermanovich (2011a, 2011b) noticed elementary teachers benefited significantly more than secondary teachers in a science professional development effort. This reflected the need for more science in elementary teacher development. University faculty from science, technology, engineering and mathematics could successfully partner with teachers to make STEM integration more meaningful in teacher professional development. See Kumar and Altschuld (2008) for an example of how such a partnership was behind a successful, NSF-funded teacher preparation project in science.

As Marder (2013) stated, though integrating science, technology, engineering and mathematics under STEM is a worthy undertaking, "we—the scientists, mathematicians, and engineers who will be asked to help implement the new standards—do not ourselves always possess the full set of skills that STEM education will ask of our students" (p. 150). Morever, in an overcrowded curriculum, pressuring teachers to find time for cross-disciplinary themes and activities in STEM is a complicated matter that needs carefully thought-out professional development efforts, regardless of elementary, middle or secondary level. Since school districts evaluate teacher performance, they must be involved in professional development so that teachers are not set up to fail -- asked to do one thing, and then evaluated on something else.

Limitation of appropriate contexts where multiple competencies from the STEM disciplines can overlap poses an obstacle to successful STEM implementation (Massimo, 2015). Not every concept cuts across science, technology, engineering and mathematics. This leaves teachers with the task of hunting for overlapping contexts, limiting successful implementation of STEM in schools.

When it comes to funding STEM professional development with public (e.g., NSF) and private funds, STEM education is not without its critics. For example, according to Zakaria (2015) "consider America's vast entertainment industry, built around stories, songs, design and creativity. All of this requires skills far beyond the offerings of a narrow STEM curriculum" (n.p.). There is no simple response to such criticisms. As Zakaria (2015) continued, "America overcomes its disadvantage — a less-technically-trained workforce — with other advantages such as creativity, critical thinking and an optimistic outlook.

A country like Japan, by contrast, can't do as much with its well-trained workers because it lacks many of the factors that produce continuous innovation" (n.p.). The STEM education community should take such criticisms into account, seriously reflecting on the advantages and disadvantages of STEM education. It should approach STEM professional development with caution, especially where public funds, such as systemic educational reforms, are involved. Program evaluation plays a key role in this.

As Anderson (2002) pointed out, "the nature of systemic reform is complex and no one evaluation study has sufficient resources and time to fully investigate the breath and depth of all the components of restructuring education systems. Systemic reform involves the simultaneous restructuring of many components of the education system in order to improve simultaneously the academic performance of all students at all levels of the K-12 system" (p. 72). STEM education professional development is a complex systemic reform. Therefore, more comprehensive evaluation (Kumar & Altschuld, 2002) and needs assessment ought to be employed to determine "what is (the current status or state) and "what should be (the desired status or state)" (Altschuld & Kumar, 2010, p. 3) and to guide effective policies leading to successful classroom practices in science, technology, engineering and mathematics.

Final Note

On a final note, it is extremely important that developers of STEM professional education policies build these policies on foundations of sound, evidence-based research. If not, "policymakers are often left with no choice but to base decisions affecting science [technology, engineering and mathematics] education on the face value of what are often not-so-well-informed research and development efforts, project findings of limited scope, and personal opinions of politicians" (Kumar & Altschuld, 2003, p. 561). Likewise, contributions from fields such as the Learning Sciences in improving our understanding of learning should not be overlooked in developing effective STEM professional development policies (Kumar, 2017). STEM professional development remains a fertile field for research and development in K-12 education in the United States, and developing policies that facilitate successful STEM professional development will be critical from here on out.

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STEM Reasoning and Learning via Science Modeling and Engineering Design Challenges

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Introduction

The Trends in International Mathematics and Science Study (TIMMS) and Programme for International Student Assessment (PISA) studies have shown that many countries across the world need to improve not only student content scores in science and mathematics but also their reasoning skills (Mullis, Martin, Goh, & Cotter, 2016; OECD, 2016). The OECD has recommended that these nations consider implementing authentic practices in STEM education. Two authentic practices that could be implemented by these nations include model-based science curriculum units (Gilbert, 2004; Jackson, Dukerich, & Hestenes (2008), Passmore, Stewart, & Cartier, 2009; Windschitl, Thompson & Braaten, 2008) as well as the introduction of engineering design challenges (Zeid, Chin, Duggan & Kamarthi, 2014).

Model-Based Pedagogical Techniques

Model-based pedagogies are either based on the use of existing models to make predictions or the development of models from empirical data using a modeling cycle. Model-based science is an authentic practice as it is routinely utilized by scientists. Scientists are continually developing theoretical or empirical models consisting of multiple representations (Hestenes, 2010; Kozma, 2003).

Model-based pedagogies make use of scientific models in different ways. One model-based intervention in biology was developed by Passmore and Stewart (2002). They developed a model-based curriculum that introduced students to already existing models of natural selection. Students' were asked to deploy the models while problem solving using real world data. During these deployments students could either confirm or refute the existing models they were presented.

An empirical approach, Modeling Instruction, was developed for physics education by Wells, Hestenes and Swackhamer (1995). This program scaffolded students in the development of lab activities in order to collect data pertinent to the scientific phenomena under study. The collected data was then analyzed in order to construct a scientific model along with its multiple representations. The student generated models were then deployed during problem solving activities.

The models developed within the context of this curriculum are continually revised based upon the model's ability to be predictive in multiple contexts. But, models and modeling cycles can be defined in multiple ways.

What is a Model?

In this article a scientific model is thought to be either conceptual or mental in nature (National Research Council, 2012). Mental models can only be made visible through the conceptual model representations produced by students. These conceptual model representations allow the scientific phenomena being studied to be made more understandable as well as predictable by students through the use of these multiple representations. These representations can include, graphs, algebraic equations, verbal descriptions, pictorial drawings as well computer simulations. These explicit representations produced by students allows them to better understand their implicit mental models. An example of the scientific model of constant velocity along with some of its representations can be seen in Figure 1. Expert problem solvers can easily switch between the model representations thus improving their ability to solve more complex problems (Harrison & Treagust, 2000).

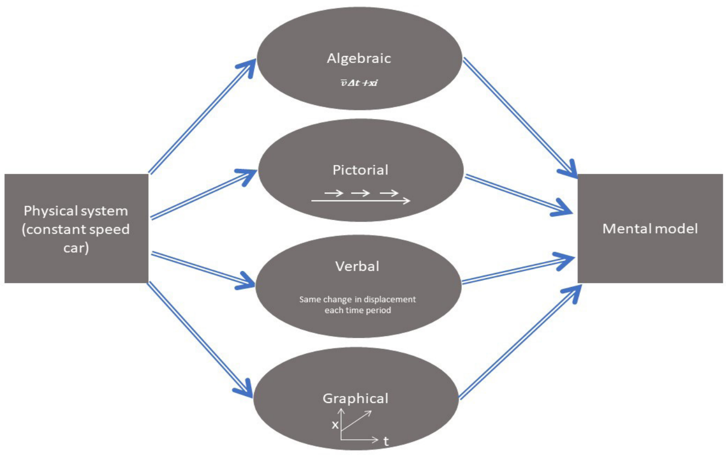

Figure 1. Constant Velocity Model and Its Representations (adapted from Dukerich, 2015)

Models and the Modeling Cycle

Scientific models and their associated representations are created within a modeling cycle. One modeling cycle that has been used extensively within the Modeling Instruction pedagogy includes model development and model deployment (Jackson et al, 2008). This simplified cycle can be expanded into a more in-depth model (see Figure 2). At the beginning of the modeling cycle students encounter scientific phenomena such as a car moving at a constant velocity. The students discuss what variables can be collected via hands-on activities. They design an experiment and collect data. Using the data collected the students can develop the scientific model along with its multiple representations. The newly developed model can then be used to predict outcomes for both the original phenomena as well as similar phenomena in different contexts. When the initial model fails students can refine the model allowing it to become more predictive in diverse situations. When the model fails to be predictive in a new situation or context the students may have to start over by developing a new model that will be predictive in this new situation. For example, this can occur when students attempt to use the constant velocity model to predict outcomes for a situation where the object is moving at a constant acceleration. In this situation the students realize after attempting to revise the constant velocity model that a new model is required. Thus they develop a model of constant acceleration.

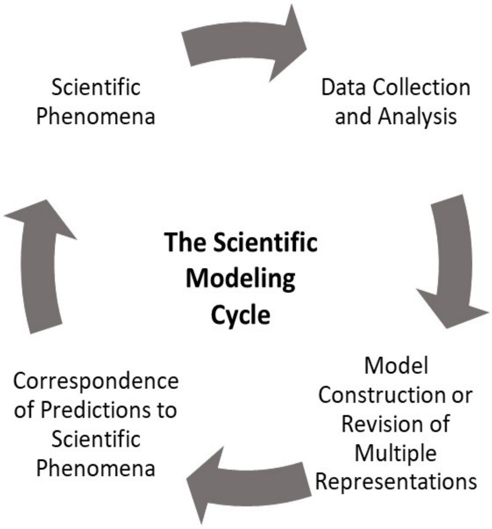

Figure 2. The Scientific Modeling Cycle

Engineering Design Challenges

Engineering design challenges have been used at many grade levels from kindergarten to university level. The challenges are developed so that they sustain student interest while making use of the engineering design process (EDP). The challenges are usually based on real-world problems for which students can construct viable solutions making use EDP and their knowledge of a variety of academic subjects. The key to a good engineering challenge is that it must be open ended enough to allow for multiple solution paths (i.e., there is no "right" answer to the problem). An example of an engineering design challenge would be to assign the problem of how to control an invasive species. This can be a complex problem that becomes even more complex when one of the constraints of the problem is that groups must have an ecologically friendly solution (Malone, Schuchardt & Schunn, 2018). Thus, engineering design challenges lead to higher order problem solving that requires the use of collaboration, communication, creativity and systems thinking. During the creation of a solution the students working on engineering design challenges discover that failure can be a positive motivator during the problem-solving process by allowing for improvements in the final prototype or process. Thus failure is an expectation of any design challenge. In addition, the challenges drive home the idea that engineers have a desire to improve the world for its inhabitants.

Engineering Design Process

The engineering design process (EDP) is an iterative process that engineers advance through when solving an engineering design challenge and producing a final solution. There is not a single process that has been approved by all engineers and EDP can range from a complicated cycle to only a few steps.

A simplified version would start with the introduction to the problem and discovering the constraints of the problem (see figure 3). This step, the asking stage, allows the team to clarify the problem as well as conduct background research into the science behind the problem. After a through understanding of the problem students can brainstorm solutions and decide on initial tentative solutions, during the imagining stage. During the planning stage, the team must propose the development of the solution by diagramming a possible solution and deciding on the materials to be utilized. After diagramming the possible solution, the team must create the prototype or process and test out the possible solution during the creating stage. Finally during the improving stage of EDP, they must determine the pros and cons of the solution based upon their testing. This leads them to understand the idea of failure which leads to improvements of the design. Thus, while improving the design they can be led to more questions and a recreation of the design moving back to the asking stage.

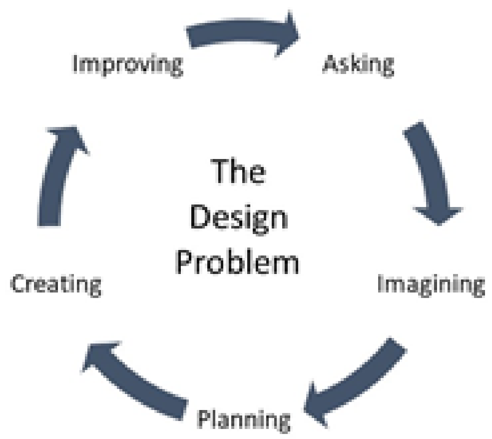

Figure 3. A Simplified Engineering Design Process

As students engage with EDP they will discover that the process can be used in multiple contexts not simply STEM fields. This new understanding of EDP gives them a problem-solving process to incorporate into their lifelong learning goals.

Adding the Arts to STEM = STEAM

The use of engineering design challenges can allow for integration of STEM concepts. However, the introduction of the arts can convert the integration from STEM to STEAM. One such STEAM integration has been attempted by the incorporation of dramatic inquiry and dance into primary school STEM curriculum units. Dramatic inquiry (DI) is a dialogic inquiry and dramatic play-based pedagogy (Edmiston, 2014) One DI approach is the "Mantle of the Expert" which positions students as expert engineers while allowing them to engage in scientific inquiry (Heathcote & Bolton, 1995). This approach allows students to take on the role of expert engineers as they attempt to solve an engineering design challenge in an authentic fashion. In addition, other components of artistic expression can also be included into the units such as interpreting the transfer of energy during a windmill engineering design challenge via interpretative dance movements. This kinesthetic approach to engineering challenges and EDP allows students to become more engaged in the STEM subjects thus heightening their interest.

The Efficacy of Authentic Practices

Several studies have shown that the use of modeling-based units and engineering design challenges at all levels of instruction have improved students' knowledge of science as well as other skills such as scientific reasoning and problem-solving.

Research Supporting Modeling Based Practices

Modeling-based practices have been shown to be effective at many different grade levels. In primary schools modeling-based practices have been used to develop students' ability to explain science concepts (Archer, Arca, & Sanmarti, 2007) as well as their use of modeling practices to reason about scientific phenomena (Zangori & Forbes,2015). Lehrer and Schauble (2005) have shown that young children can progress from modeling science ideas through the use of literal representations to more symbolic and mathematical representations during primary grades. Thus, modeling is a viable approach for students in these primary grades.

The majority of the research concerning modeling-based practices has taken place within secondary schools. In secondary schools in the United States, Modeling Instruction has been the most extensive investigated modeling-based approach to science. It has demonstrated improvements in conceptual knowledge along with declines in alternative conceptions in physics (Hestenes, Wells, & Swackhamer, 1992; Jackson et al, 2008; Malone, 2008; Liang, Fulmer, Majerich, Clevenstine, Howanski, 2012); biology (Malone, Schuchardt, & Sabree, in press) and chemistry (Malone & Schuchardt, 2016).

A similar modeling-based approach that incorporated engineering design challenges also demonstrated an increase in student conceptual knowledge over the course of a unit (Malone et al, 2018; Schuchardt & Schunn, 2016).

Multiple model-based practices in science have also demonstrated an increase in the use of multiple representations in multiple subject areas (Harrison & Treagust, 2000, Malone, 2008, Malone et al, 2018, Tsui & Treagust, 2013). Multiple representational use might be the key factor to the improved problem solving and metacognitive skills developed by Modeling Instruction physics students observed by Malone (2008). The improvement of scientific reasoning skills when modeling-based practices are deployed have been observed by several researchers (Coletta, Phillips, & Steinert, 2007; O'brien & Thompson, 2008; Schuchardt et al, 2008). These model-based practices have also demonstrated increases in students' modeling skills in chemistry (Dori & Kaberman, 2012) and in biology (Passmore & Stewart, 2000).

Research Supporting Engineering Design Challenges

Engineering design challenges have been used effectively at many different grade levels. The use of engineering design challenges has produced conceptual gains in biology and physical science at multiple levels of schooling including college (Sahin, 2010), high school (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Ellefson, Brinker, Vernacchio, & Schunn, 2008; Malone, et al, 2018; Zeid et al, 2014), middle school (Mehalik, Doppelt, & Schunn, 2008) and elementary school (Lachapelle, Oh, & Cunningham, 2017). The use of engineering design challenges have also produced increases in scienctific reasoning skills in eighth grade students (Silk, Schunn & Cary, 2009), mathematical understanding of secondary schoool students (Hernandez et al, 2014; Schuchardt & Schunn, 2016), and student engagement at all levels (Doppelt, Mehalik, Schunn, & Krysinski, 2008; Lachapelle & Cunningham, 2017; Malone, et al, 2018). The integration of dramatic inquiry and other artistic endeavours with engineering design challenges has demonstarted an increase in elementary students' understanding of engineering, tehcnology and science concepts (Tiarani, Irving, Malone, Giasi, & Kajfez, 2018).

Discussion and Implications

The authentic practices of scientific modeling and engineering design challenges have been shown to improve student abilities in a multitude of areas. The incorporation of these practices within classrooms at all levels of schooling should affect the expertise of students in terms of content, problem-solving and reasoning skills. By enhancing students' abilities in these areas, we can produce competent science students ready to be lifelong learners and successful STEM college students. In fact, there is a strong correlation between higher scientific reasoning ability and success in STEM courses both in college and high school courses (Coletta & Phillips, 2005; Coletta, et al, 2007). A concerted effort to implement these authentic practices at all grade levels should allow for the production of a strong STEM pipeline ensuring the necessary STEM professionals for the future development of all countries.

Conclusion and Recommendations

The implementation of authentic practices given the knowledge that success in STEM courses is correlated to scientific reasoning ability makes their incorporation into STEM classes worldwide an equity issue. If we want all students to succeed to their utmost, then authentic practices of STEM education must be incorporated at all educational levels. The incorporation of these practices will lead to a worldwide populace that are STEM literate and ensure economic growth. However, to realize these goals research must be enacted in order to determine how best to implement modeling and engineering at all grades. In addition, longitudinal studies should be conducted to determine the effects over time on the use of authentic practices across multiple grade levels.

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An Overview of STEM Education and Industry 4.0

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Introduction

It is known that the changes in science, technology and engineering have been increasing in recent years. We understand these changes by looking at both scientific studies and inventions, new technological tools and machines and new methods which have been used in the engineering fields. From this point of view, it is able to be claimed that education systems are changed to be adopted new changes which have been seen in industry, as well. STEM education can be identified as one of new approaches to be used in education system, which also aims students to be able solve problems in their daily lives. Meanwhile it is thought STEM education must be introduced. There are some different STEM concept defines in the literature. National Reserach Council (1996), STEM is an educational and teaching approach which integrates the content and skills of science, technology, engineering and math. Herschbach (2011), states that STEM is being created by using capital letters of science, technology, engineering and math. At this point, it can be asked why countries need STEM Education and need STEM activities and applications in their education systems. To answer this question, U.S. former president Barack Obama's call to action on new developments in Industry of USA's education system can be said the reason of changes. He said "One of the things that I've been focused on as President is how we create an all-hands-on-deck approach to science, technology, engineering, and math. We need to make this a priority to train an army of new teachers in these subject areas, and to make sure that all of us as a country are lifting up these subjects for the respect that they deserve" (White House, 2013). After Obama's talk on STEM Education there were seen efforts in the USA's states. The similar efforts can also be seen in European Union (EU) and EU paid attention more efforts on STEM Education and EU (created many STEM projects such as Scientix, STEM Alliance and so on. STEM projects have also been continued by EU and European countries. At this point, the relationship STEM Education and Industry should be explained. In this context, the skills of STEM education can be stated to understand the relationship between STEM Education and Industry 4.0. The Partnership for 21st Century Skills (2011), defines 21st century's skills "collaborating, communication, critical thinking and creativity. National Research Council (2010), states 21st century's skills "nonroutine problem solving, self-development, systematic thinking, adaptability and complex communication skills. Besides them, innovation, employability and efficient team working can also be given as 21st century's skills. The 21st skills are paid attention which we are able to understand it by Obama's statements regarding USA's efforts toward STEM Education. It is clearly understood that 21st century workforce need people who are donated with 21st century skills. Gonzales, Jones & Ruiz (2014) also revealed the importance of STEM Education and its features related to industry. In their opinion completion of the first 21st century decade launched a global competitiveness pace in economical markets which had initiated an instructional paradigm shift for learning and teaching. Banks & Barleks (2014), STEM learning carries out in the real World, in this context schools work with industry including other learning centers. World Economic Forum (2016), points out according to a popular expectation that 65% of children who entering primary school today will ultimately end up working in completely new job types that do not yet exist. European Commission/EACEA/Eurydice, (2016), states that improving and promoting entrepreneurship education is one of the key policy objective for the EU and it provides skills, knowledge and attitudes that are developing an entrepreneurial culture. It is thought that the introduction of Industry 4.0 is necessary. Wang et. al. (2016), states that Industry 4.0 is the proliferation of cyber-physical systems that introduces the fourth stage of industrialization. It is useful to be given Industrial revolutions which facilitate the relationship between STEM Education and Industry. In the figure 1, the development of industry is given since 1784 till now.

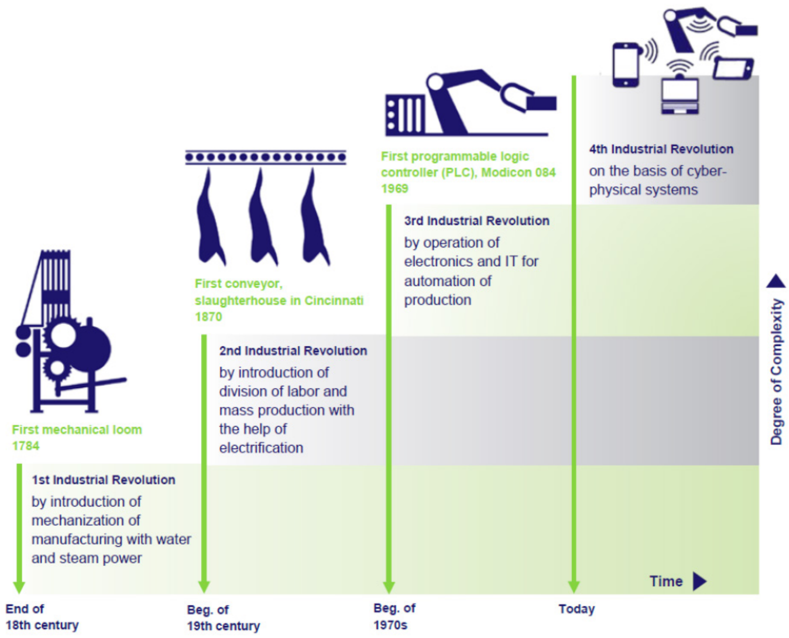

Figure 1. The Four Industrial Revolutions (graphic by Kagermann et al., 2013)

As it can be seen by looking at figure 1, first industrial revolution initiated by using steam water in the industry, the requirement energy was provided by manufacturing with water and steam power. When entering 19th century, second industrial revolution started by using electrification in the industry. Second industrial revolution lasted to 1970s, then, third industrial revolution started by operation of electronics and IT for automation of production. After all, today, we are mentioning about Industry 4.0, because it is on the basis of cyber physical systems. Technology and its applications which are used in Industrial fields have been changing in time. Kurfuss (2014), describes all Industrial revolutions processes. It states that first industrial revolution was driven by the advent of steam engines being used to power production facilities. Second industrial revolution was driven by the assembly line, exemplified by Henry Ford a century ago. Third industrial revolution, which occurred in the 1970s, was driven by the use of computers in production. For instance, the use of CNC machines, computer processing of quality and logistics information, were transformed during the 3rd industrial revolution. Valdez et. al (2015), describes Industry 4.0 is a paradigm shift in manufacturing technology.

It is seen that there have been carried out some studies within Industry 4.0. European Parliament (EP) (2016), Industry 4.0 was initially coined by the German Government. Stock and Seliger (2016), presents an overview of different opportunities for sustainable manufacturing in the scope of Industry 4.0. Germany Trade & Invest (2017), states that "Industry 4.0" or "Smart Industry" refers to the technological evolution from embedded systems to cyber-physical systems. It also represents the coming fourth industrial revolution on the way to an internet of things, data and services. EP (2016), states that Industry 4.0 has main features. These are "Interoperability, Virtualisation, Decentralisation, Real-Time Capability, Service orientation and Modularity".

Figure 2. Technologies of Industry 4.0 (TÜSİAD, 2016)

The elements of Industry 4.0 are the cloud, additive manufacturing, augmented reality, big data and analytics, autonomous robots, simulation, horizontal vertical system integration, the industrial internet of things and cyber-security. Industry 4.0 has nine advanced technological products and already some of them have been using in manufacturing.

Rüßmann et. al (2015), But it can be said that with Industry 4.0, those given technologies transform production: isolated, fully integrated, automated and optimized production inflow; changing traditional production relationships among producers, and customers and suppliers between human and machine. Although there have been created some studies which integrates both STEM Education and Industry 4.0, it can be seen that they are not enough. It is also known that some of them are not directly linked to each other. Flynn (2012), investigated the relationship between STEM principles for advanced manufacturing education. West (2012), examined that how Australian universities could be best prepare STEM graduates in the scope of in the academic researches and economy. Landivar (2013), investigated the relationship between science and engineering education and employment in STEM occupations. SIEMENS (2017) investigated in its study, the relationship between STEM and Industry 4.0 and it was highlighted them importance of STEM in integrating Industry 4.0. When we focus on both Turkish STEM Education situation and Industry 4.0, it is seen that there have been prepared some reports and studies by private institutions and public institutions. TÜSİAD (2014) prepared a report, it highlighted the importance of STEM Education for future, within STEM Education and its relationship with Industry. Ministry of National Education (2016), states the significance of STEM Education within the scope of future jobs.

STEM Education and Industry have been paid attention to provide people having 21st century's skills. At this point, it is very important to focus on Turkey's situation on Industry 4.0 and STEM Education. It has been seen that there have been carrying out some studies which have been creating both by public and private institutions. However, it is also seen than these studies are not enough and it has not affected STEM Education system in Turkey. A report conducted by Turkish Ministry of National Education (MEB, 2016), also highlighted similar views. It states that STEM Education should be more considered for the future of Turkey and should also be integrated with Industry. European Comission (2016), vocational and training is precious for feeding job-specific and and transversla skills, fascilating the transition to employment and maintaining and updating the skills of the workforce.

World Economic Forum (2017), several countries in the Middle East and North Africa region have also been investing in technical and vocational education and training (TVET), notably Egypt and Turkey, although this particular form of education remains under-used across the region. There can be seen some studies related to Turkey's current situation on its education system and workforce. Turkish Industry and Business Association (2016), estimated that growth targets will be realized, in this context, the need for labor employed in industry will increase and also this labor force will be more skilled. Turkey Scientific and Technological Research Institution (2016), states that challenges of Turkey within smart technology are "need for higher skilled labor force, premature de-industrialization and low export share of high-tech products." World Economic Forum (2017), quality of Turkey's education system is under Word Average

(3.8) and potential impact of job automation may be challenging. It is estimated that 52% of all work activities are susceptible to automation.

There are some international exams carried out such as PISA, TIMSS, PIRLS. PISA is an international important exam since countries are able to see their position their current situation within science, math and reading. PISA is carried out every three years (OECD, 2017). To be able to understand Turkish students' skills in science, math and reading, PISA 2015 scores are important indicators for the educators and policy makers and it gives concrete evidences to link between current STEM Education and Industry in Turkey. Some countries' PISA 2015 scores are given in table 1.

Table 1. PISA 2015 Results of Top Five Countries and Turkey

	Science	**Math**	**Reading**
1.Singapore	556	564	535
2.Japan	538	532	516
3.Estonia	534	520	519
4.China (Taipei)	532	542	497
5.Finland	531	511	526
OECD Average **Turkey**	**493** **425**	**490** **420**	**493** **428**

According to PISA 2015 results, Turkish students' science test average was 425; math average was 420 and reading test average was 428. It can be seen that Turkish students' scores within those mentioned subjects are under PISA averages (OECD, 2016). Turkish students' math, physic, chemistry and biology test scores are not expected level in a national examination which is called "Examination of Bachelor Placement". Turkish fourth grade high school students' math average is 10.38 (under 50 questions); physic average is 5.48 38 (under 30 questions); chemistry average is 10.56 38 (under 30 questions) and biology average is 8.5 38 (under 30 questions) (ÖSYM, 2016). It is able to be said that Turkish students cannot transfer their knowledge within those subjects into their life. This result also means that many of Turkish students have not had 21st skills. Due to these given reasons the study can be said it is an original study which have not been studied yet.

So, it also promotes academic studies which are directly linked both STEM Education and Industry 4.0. After all, aim of the study is to investigate the current situation of STEM education and Industry 4.0 in Turkey.

The Data of the Study

The data of the study were taken both international and national references such as articles, reports, doctoral dissertations and statics of Turkish Education System and Turkish Industry System. The obtained data from Ministry of National Education's studies and reports and from other ministries, international exams' reports and results gave very important knowledge for the study.

In this study the data were analyzed through document analysis. Within this context, 191 articles were investigated within STEM education, 16 articles were investigated within Industry 4.0. 25 doctoral dissertations were looked into which were prepared based on STEM education and totally nine international reports were investigated within STEM education and Industry 4.0.

Table 2. The Data of the Study

	PhD Dissertation	Articles	Reports	Books	Total
STEM Education	25	191	9	3	228
Industry 4.0	-	16	8	1	25
STEM Education and Industry 4.0	-	5	2		7

The data of the study is given in table 2. The finding of this study have been obtained based on these studies that are already given in table 1. According to the table 1, totally 260 academic studies were investigated and analyzed to create of the data of this study. Including academic studies carried out at national and international level, both national public institutions and private institutions' report were considered, as well.

What Have Been Found?

As mentioned previously, STEM studies have been increasing in Turkey. Although this result, it is not enough for a Turkish education system since Turkey has 80 million populations and it has to be ready for Industry 4.0. It is claimed because Turkish students' science, math and reading achievements are not at expected level. It can be seen by looking at both national and international exams' results such as PISA, TIMSS and TEOG. There are some indicators which help us to understand the current situation of STEM Education in Turkey.

By looking at the data which has include top 1000 high school students' choice the placement of STEM fields can help us to understand the position of STEM fields choice in Turkey.

All engineering fields, computer sciences, mathematical sciences and scientific fields have been included in STEM fields jobs. Medicine sciences have not been included in STEM fields. National Science Foundation (NSF), which is the great association and supports STEM fields, also do not include Medicine into the STEM fields (NSF, 2015). In figure 1, it can be said that the STEM fields placement have been changing and it has a wave.

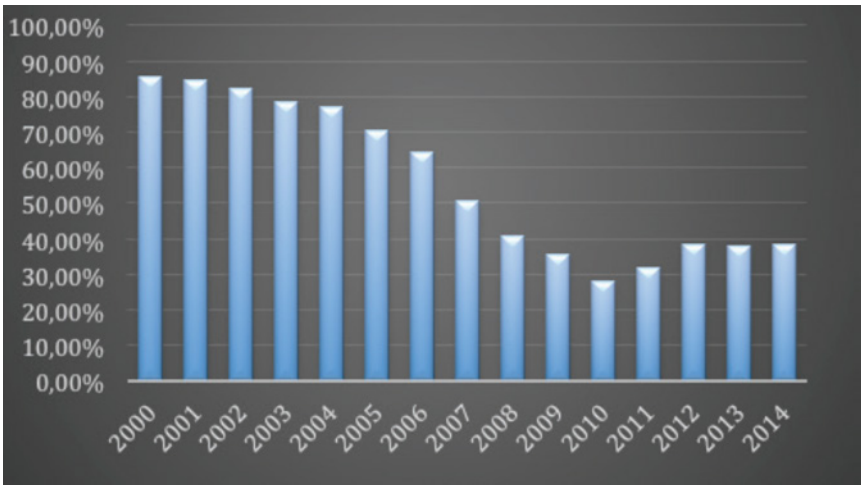

Figure 3. The Ranking Placement of Top 1000 Students in STEM Fields Within SSPC (Student Selection and Placement Center) Akgündüz et al (2015),

It is seen that the STEM placement was 85.63 % in 2000; 27.88 % in 2010 and 38.23 % in 2014. The choice of STEM fields career have been tried to be promoted in USA and European Countries, within this scope there were set up some STEM organizations and associations both in USA and in EU. Those organizations create some STEM projects which aim to get students toward STEM fields. It is expected that having 21st century skills for a society or country will be very important to conduct Industry 4.0. The skills of 21st century are "critical thinking, effective problem solving, innovation, creativity, team working, communication and collaboration". This result shows us there must be taken necessary precaution in STEM fields choice and it is also necessary to encourage STEM career. There is a report that confirms results which are given in the figure 3.

World Economic Forum (2017), stated in its report that the World Economic Forum's Future of Jobs analysis had found that by 2020, 21% of core skills in the countries of the Gulf Cooperation Council and 41% of those in Turkey are going to be different compared to skills which were needed in 2015.

Vocational high schools and technical high schools are important organizations for Turkey so that they support industrial firms' labor. We have some interesting results of students, who have studied in an industrial vocational high schools. Within the scope of LYS 2016. According to results, 40.225 students participated to this exam and their both math and science average was 160,98, while Anatolian's high school students average was 221.785 and science high schools students' average was 360.409 (ÖSYM, 2016). There are some international studies which are focused on Turkey's industrial organizations.

King of Netherland (2017), found some findings on the awareness among Turkish companies regarding Industry 4.0 and it reveals that 22% of the companies have extensive knowledge, 59% has general knowledge and 19% have no knowledge about such developments.

This result is similar with ÖSYM's results of vocational students' in Turkey. Because, vocational students' 21st skills are important for Turkish future Industry to have much more quality within Industry 4.0. It is unfortunately seen that Turkish vocational high school students' achievements are not located at desired level. At this point, an international study carried out by OECD (2009), can be given to support previous results of the study.

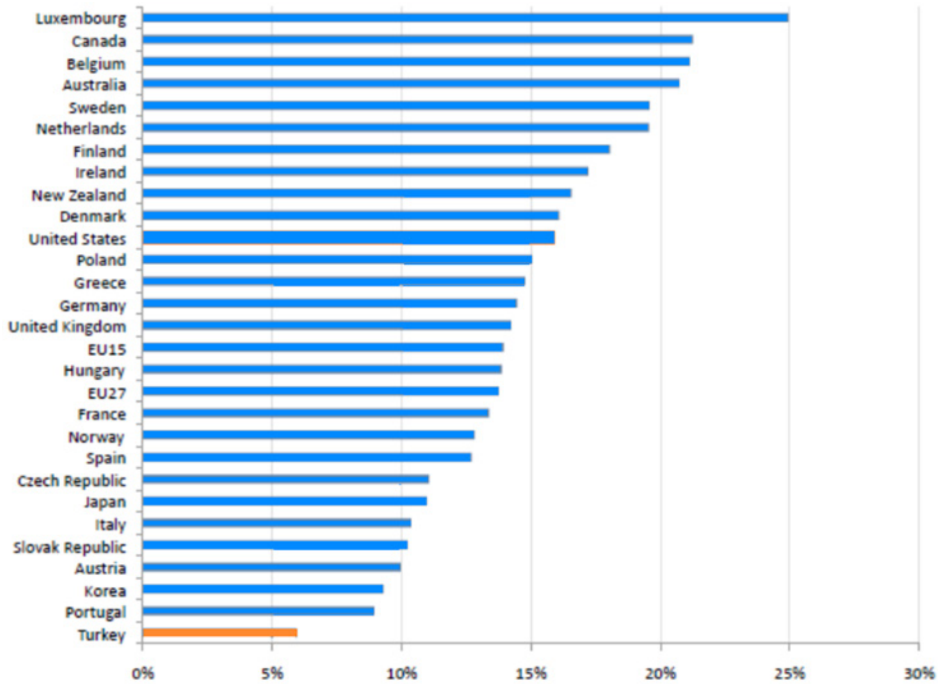

Figure 4. Share of Workforce in Science and Technology Occupations (2008)

The share of workforce was investigated in a study carried out by OECD (2009), it presents us to understand share of the workforce in science and technology occupations among 30 countries. It is seen that Turkey is located at the end of the ranking within share of the workforce in science and technology occupations. This result is seen that is suitable within Turkish students PISA 2015 scores in science and math.

Another important indicator within current STEM Education situation in Turkey is STEM organizations and their studies. Turkish universities must have important roles to promote STEM Education and to link between STEM Education and Industry. It has been found that there have been created some STEM centers in some Turkish universities. It has been understood that there are four STEM centers which were created by four universities. The first of it was set up in 2014 in a private university. When we focus on business sector's efforts for STEM Education within Industry 4.0, it is able to be said that TÜSİAD has conducted some studies which are related STEM Education and Industry 4.0. In its first report (TÜSİAD, 2014) on STEM Education, it portrays a frame for the STEM Education. Actually in all these studies, TÜSİAD tries to reveal the current situation of STEM Education and what will be done to promote Industry 4.0 in the future for of Turkey.

There are some national public organizations that they prepare reports and publish articles and they launch some calls on Industry 4.0. The Scientific and Technological Research Council of Turkey (TÜBİTAK) is one of guide, which has launches many calls, publish studies and support both public and private national institutions within the scope of STEM Education and Industry 4.0. TÜBİTAK (2016), reveals that there have been carrying out some workings within Industry 4.0 which we can understand it via its Tenth Development Plan. The tenth development plan defines those strategic features:

*Qualified people and strong society,

* Production based innovation, high growth with sustainability,

* Livable places and sustainable environment,

* To have development providing international cooperation

We are able to understand by looking at those features that those given features already present the aim of STEM Education and presents 21st century's workforce. It can also be claimed from this plan that if desired Turkey has a strong Industry in the future, Smart Industry or Industry 4.0, Turkish people have to have those features.

King of Netherlands (2017), TÜBİTAK prepared a roadmap within Industry 4.0 for Turkish Industry. It is defined that technology is devoted three groups following: "Digitalization, Connectivity and Future factories". In this roadmap, the content of Industry 4.0 are framed very well. There have been stated some highlights on advanced manufacturing in TÜBİTAK's national call for 2016 and 2017; Additive Manufacturing: Multilayer additive manufacturing, Rapid prototyping and 3D printing Technologies, CAD/CAM, simulation & modelling software, Robotics and mechatronics, Flexible manufacturing. Within the scope of Internet of Things, it is emphasized Sensors and sensing systems, Virtualization, M2M communication and Cloud computing.

All those given applications are included in ındustry 4.0. It has been found that there is no model that it reveals the relationship between STEM Education and Industry 4.0. To link between STEM Education and Industry 4.0, it is given a model, it has been created by the author, which explains the relationship between STEM Education and Industry 4.0

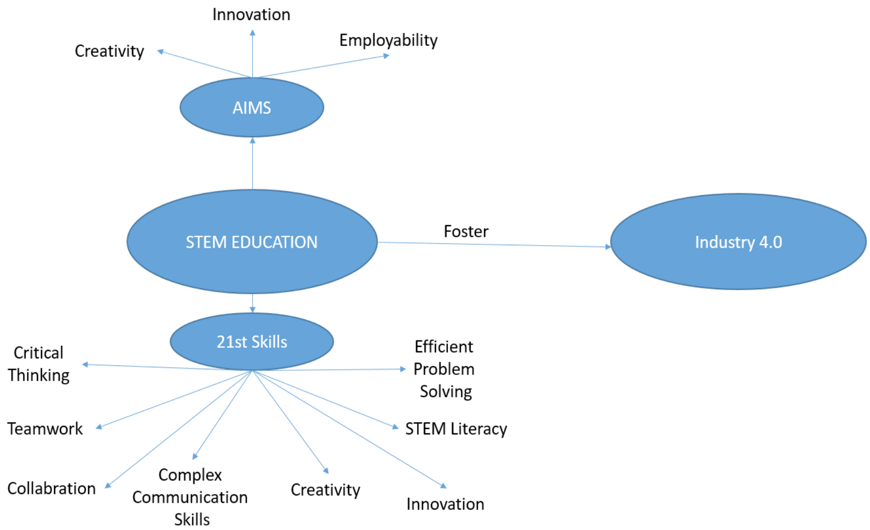

Figure 5. A Model That Shows the Relationship Between STEM Education and Industry 4.0

In this model, it is seen that STEM Education fosters Industry 4.0 with its aims and 21st skills. It can be understood from the model that STEM Education should be enhanced to have high quality industry for a country, this can be claimed especially for the Turkey. Some 21st skills and STEM Education's aims are very important to have high quality Industrial System within Industry 4.0. Another significant indicator is to link STEM Education's aims and 21st skills. Within this context, they are necessary to be linked to STEM Education so STEM Education can foster Industry 4.0.

Conclusion

In this study, it has been focused on to set up the relationship between STEM Education and Industry 4.0 and within this scope to define the relationship and current situation in Turkey. It has been reached that Turkish education system must consider the role of STEM Education to reach Industry 4.0. PISA 2015, TIMSS 2015 and LYS 2016 results within science, math and reading fields have showed us that Turkish students are not placed at expected level among other countries in terms of achievement of these fields (OECD, 2016, ÖSYM 2016). Killingsworth (2014), states that industry certificate is necessary into a skilled-level position in a technology or engineering field.

Gonzales (2010), revealed in his study how global economy motivated both federal and state governments with private industry to enhance the improvement of STEM academies. Lars, et al. (2015), state that the manufacturing industry has been continuing to be a central driver of growth for economies worldwide and in the Industry 4.0 concept, it is necessary for workers make themselves ready for the new fields of modern smart manufacturing. Boyd & Tian (2016), reveals that capable workers, who have expertise in

STEM, are deemed main fort he researches and development activities which stimulate economic growth. In Turkey, there are many STEM Centers, which claim that they donate students with 21st skills and give STEM Education. As mentioned in the previous section that most of them actually do not give STEM Education and it is already clearly seen that they are not able to give those educations due to their lack of competent in STEM Education. Atkinson & Mayo (2010), state that producing more and better STEM graduates is going to require new institutions; especially new specialty science high schools and new kinds of programs and even colleges at the BS level.

Although there have been carrying out some limited studies, projects, it is seen that vocational technical high schools are not supported sufficiently within STEM Education and Industry 4.0. Vocational high school students should be supported to create new projects linked to STEM Education and Industry 4.0' fields, especially. There are some studies related this study. Hughes (2013), states in her study that partnerships with industry may be strong enough opportunities for students to investigate fields of STEM disciplines. Kerr (2013), both industry and education are key pieces in the STEM puzzle.

The integration STEM Education with Industry should be provided to have much more skilled people, who are equipped with 21st century skills, in 21st century. It can be given an example that is directly related do this statement. The Guardian (2016), revealed in its news that Australian high school students made a drug to treat malaria disease. In the process, it was understood that they have collaboration, team working, effective communication, critical thinking, innovative approaches, entrepreneurship. Besides it has been understood by the news that students could manage to produce the medicine cheaper than other medicines, which are already used by people. This means students' medicine can support employability for people in the future manufacture.

Recommendations

*STEM Education studies should be organized by Ministry of National Education and Turkish Universities in collaboration. It means all STEM studies can be carried out professionally at national level.

*STEM centers could be found and STEM experts can be provided to work in these centers. They can be supported with real STEM materials which are linked with Industry in order to make a real STEM Education and to donate students with 21st century's skills.

*The relationship between vocational high schools and Industry should be carried out by using STEM Education and its applications to reach Industry 4.0' features.

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