Re-Aligning Approaches for Successful Implementation of STEM Education in Today's Elementary Schools in Developing Countries: Policy Commitments and Practices

John fungulupembe Kalolo
MKWAWA UNIVERSITY COLLEGE OF EDUCATION

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John Fungulupembe Kalolo[1]

Abstract

Providing all students with access to effective science, technology, engineering, and mathematics (STEM) education is important for all nations' competitiveness. Several high-profile proposals are increasingly presented by both academic and business communities to address the need for successful implementation of STEM education in todays' schools. Different nations are therefore in a rally to find out appropriate approaches for successful implementation of STEM education in schools. However, the achievement of this desire has not been easy for most of countries as it has been clouded by various dilemmas regarding the best ways for successful implementation of STEM education. This study aimed at identifying various promising approaches for the successful implementation of effective STEM education in developing countries. Specifically, the study focused at examining how policies, commitments and practices can be aligned for successful implementation of effective STEM education. This discussion is important in that it reveals many issues that explain what it takes to having an effective STEM education.

1. Introduction

STEM education is a broad reform based movement in the areas of mathematics, science, technology, and engineering that seeks to cultivate a STEM-proficient workforce and a STEM-literate citizenry to increase the states' competitiveness in the global economy (Schmidt, 2011). Increasingly, definitions of STEM also include reference to an interdisciplinary approach that aims to cultivate a deeper understand of each subject through an emphasis on the interrelated nature of mathematics, science, technology, and engineering.

The other realm of educators identify STEM education as a non-traditional education system that shifts students away from learning discrete bits and pieces of phenomenon and rote procedures toward investigating and questioning the interrelated facets of the real world (Smith, & O'Day, 1991). The STEM fields appear to be treated as facets of the whole in a sense that the whole may be greater than the sum of its parts. The merging of different areas of STEM is crucial in that when explicit instruction does not make connections across STEM disciplines, isolated disciplines may prevent students from building necessary competencies and connections among the four areas of STEM. In such integration each discipline in STEM has its own role in the meaning of whole. For example, mathematics has been identified as the language of science, and engineering and technology as integral parts to science (Kuenzi, 2008).

Though there is an evolving need to treat STEM fields as whole, more often these fields seem to be treated separately, and science and mathematics being the subject of the most research (Hanover Research, 2011).A consensus exists that improving STEM education in today's schools especially in developing countries is a necessary condition for preserving the country's capacity for innovation, discovery, improving, economic strength and competitiveness in the international market place of the 21st century.

[1]A lecturer at Mkwawa University College of Education of Education, Iringa, Tanzania

What students learn in these disciplines has shown to shape their intellectual development, opportunities for future study and work, and choices of career, as well as their capacity to make informed decisions about political and civic issues about their own lives. Different studies have revealed that a wide array of public and personal issues ranging from global warming to medical treatment; from social networking to daily community lives require knowledge of STEM (By bee, 2010; Thornburg, 2008). This is to say, solutions to some of the most daunting problems facing different developing countries today require not only the expertise of top STEM professionals but also the STEM literacy of its citizens.

Despite the few clear indicators of success on the implementation STEM education in some of schools in developing countries, there are compelling reasons for concern about quality and effectiveness of the education that many students receive in these disciplines (Sorenson, 2010; Wilson, 2011). When compared to other nations, the provision of effective STEM programs to students in developing countries appears to be not successful in that large majority of students still fail to reach adequate levels of proficiency in STEM (Lip &McNeill, 2009). Although all too much is known about why schools may not succeed, it is far less clear what makes STEM education effective. Policy makers and education partners agree on the need to identify strategies and approaches for successful implementation of quality STEM programs so that these models for best practice can be replicated.

The intention to carry this desk based review was built around the premise to identify the promising approaches or practices for successful implementation of STEM education in schools. Following other developed nations that continue to gain ground in preparing their students in critical fields of STEM, the developing countries appear to be in a pressure to explore variety of ways to inspire future generations in STEM education. This review explored some of those ways. The review discusses about how such approaches can be used to guide the practice in STEM education in developing countries. It should be understood that, it is not possible in a short paper like this to cover all the four areas of STEM in depth. However crucial insights about the topic will be covered at various points in the paper.

Defining the Concept “Success” in STEM Education

Success in education is defined in varied ways and in many cases it is contextually defined. Means andPenuel (2005) outlined three key questions and issues that need to be considered in determining the success of any undertaking. These include: What is “success”? How is it judged? What are the elements of success? In the context of this study success is defined as an indicator of the best STEM schools with large numbers of well-prepared and highly motivated STEM students. Success in this context is not only judged by looking at how many successful graduates are produced, or average achievement, but also on how effectively the achievement gaps between different groups are narrowed. Different elements appear to be commonly used to identify successful STEM schools or programs. These include:

- The context in which education takes place. This determines the curriculum, the resources, the priorities, and students’ expectations and motivation.
- The program’s specific goals, such as preparing top students for advanced study and challenging careers, reducing achievement gaps, and/or improving math and science literacy for all students. This dictate the standards used to judge the programs efficiency.
- Structural difference of schools and programs. This determines the specific conditions and practices within programs.
- Test scores in STEM, course taking, school readiness and performance in STEM, choice of STEM as major study, and performance in the workforce.

Striking Statistics: The Need to Improve STEM Education

STEM education has many potential benefits for individual learners and for the nation as a whole (National Research Council {NRC} (2011). One of the crucial roles of STEMeducation is the development of personal well-being of each citizen and for the nation’s competitiveness in the global economy (NRC, 2011). It is unquestionable fact that whether the initiative to provide quality STEM education is geared at preparing students for advanced degrees in STEM or ensuring that the community has the scientific and mathematic literacy to strive in the 21stcentury technology-based economy; the foundation for both of these need to begin at schools(Hanover Research,2011).

Effective STEM education (and competitiveness) has received much attention in recent years. Several studies have been written and catalyzed a rigorous conversation among leaders in education, business, industry and politics about how best can STEM education be delivered in schools (NGA, 2007; Noha, 2013; National Research Council, 2011). Many of these conversations have led to the conclusion that challenges the traditional science education systems to think of including the forgotten aspects of technology and engineering education. The need to improve STEM education in most developing countries is therefore being reflected not only in a growing demand for their students to be on par with peer developed and competitive countries around the world but also the need to solve immense challenges in critical areas of energy, health, environmental protection, communication, and national security.

Studies indicate that between 50 and 85 percent of growth in the gross domestic product in the world can be accounted for by advancements in STEM education (Bybee, 2010; The National Governors Association's {NGA}, 2007; Tsupros, Kohler, & Hallinen, 2009). Also the issues of economic prowess, scientific power, and national security all appear to depend on the status of STEMeducation in schools. Again more than 75 percent of all jobs in recent era involve either engineering or information technology related tasks, the situation that demands education system to revisit how it addresses STEM education in school systems (NRC, 2007). Also the research evidence predict that 16 out 20 occupations with the largest projected growth in the next decade are STEM related and that only four of the STEM-related occupations with the largest projected growth require an advanced degree training (Institute for Higher Education Policy, 2007;NRC, 2011).

The other need for effective STEM education is derived from constant changes, emerging needs, and expectations of the stakeholders towards STEM output, a situation that demands a reform on how STEM education can be aligned for its successful implementation in schools. Additionally the research evidence shows that STEM education has not been successful in generating the next scientists, technologists, computer programmers, ecologist, environmental scientists, geologists, mathematicians, meteorologists, statisticians, zoologist, and science, or technology teachers, engineers, just to mention a few who can create new inventions and lead the development of sustainable digital era (PCAST, 2010). Contemporary STEM education in developing countries practices have shown little impact in inspiring students to choose STEM careers such as aerospace, architectural, biomedical, chemical, civil, electrical, and network engineers along with biological, chemical, construction management, mapping, simulator maintenance, and survey technicians (Council on Competitiveness, 2005;Kaufman, Moss, &, Osborn, 2003; Noha, 2013).

As such, solutions to all the aforementioned challenges in STEM education, requires a coherent and coordinated effort from all the four disciplines in STEM to address the challenge. It is very likely that those solutions will rely heavily on the knowledge base in science and mathematics as well as quality of STEM of education offered in schools (The Oregon STEM Education Initiative, 2011; West,2012).The need to improve the STEM education is also based on the idea that today's world requires that all students obtain a solid foundation in STEM because virtually every job requires proficiency in applied technology, mathematics, and science.

The Aim of Study

This review paper attempted to explore, through an examination of existing research, reports, policy and publicly available information about various promising approaches for the successful implementation of quality STEM education in developing countries. The analysis provides a review of research relating to how policies, commitments and practices can be aligned for successful implementation of quality STEM education. Specifically the review intended to:

i. Identify the status of STEM education in today's schools in developing countries

ii. Examine the issues facing this region with regard to successful implementation of STEM education.

iii. Identify promising interventions/approaches for successful implementation of STEM education in schools.

It is not the intentions of this paper, however, to identify dogmas but rather the promising practices through which different schools in developing countries can live up to their desire for successfully implementation of STEM education in schools. In the following sections the paper briefly addresses the methodology employed in this paper.

2. Methodology

The methodology of this review paper incorporated a combination of literature reviews, desk research, web searches, and analysis of publicly available databases. The methodology acknowledges the literature, governmental and nongovernmental reports, bodies, organizations, policies, initiatives, schemes, and programs relating to STEM activity at all levels of education. The plan of analysis included:

- A review of existing innovative, new and emerging initiatives, programs and practices for improving the STEM education in schools.
- A review of academic research, reports and publications which have attempted to pay way towards promising approaches for successful implementation of STEM education.
- A review of various reports that have attempted to highlight, quantitative and empirical evidence on how STEM could be realigned towards successfully provision of effective STEM education.

The review sets out to propose promising approaches for successful implementation of STEM education in schools in the developing countries. It is envisaged that the discussion from this article will help in closing the knowledge gap between aspirations versus success in providing effective STEM education in schools.

This review article has four parts. The first part provides a comprehensive definition of STEM and its importance in the region's socio-economic status. The second part discusses the need for STEM education in developing countries. This section also outlines the existing gaps in the implementation of STEM education. Part three discusses the challenges for successful implementation of STEM education. Part four identifies the promising interventions for successful implementation of STEM education. The final part provides a conclusion of the article as well as suggestions of areas for future research.

3. Nature of STEM Education

The acronym "STEM"was firstly mentioned around1990s by the National Science Foundation (NSF) and it was identified from the acronym "SMET" shorthand for "science, mathematics, engineering, and technology (Sanders, 2009).SMET was later changed to STEM because one of the NSF program officer complained that "SMET" sounded too much like "smut, a situation that led to the birth of acronym "STEM" shorthand for science, technology, engineering, and mathematics. Since then STEM has been defined in different ways (Salinger & Zuga, 2009). For example there are some who identify STEM by the separate subjects of which it is composed, while others look at it as an integrative approach to curriculum and instruction(Bybee, 2010). Studies reveal that the later view is the correct one because it removes any boundaries between the disciplines composing the acronym and thus allowing an interdisciplinary view which allows different science disciplines being taught as a single subject (Salinger & Zuga, 2009; Morrison & Bartlett, 2009). The "STEM" education is therefore an interdisciplinary reform that seeks to integrate, in whole or in part, the four areas of science, technology, engineering, and mathematics into a comprehensive and coherent curriculum across content areas.Such an interdisciplinary approach towards STEMeducation makes this undertaking crucial to nation's economic competiveness and youth's ability to succeed in the 21st century. This assertion is made plausible by the Colorado Department of Education that describes STEM as, An interdisciplinary approach to learning whereby rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering and mathematics in context that make connections between school, community, work, and the global enterprise, enabling the development of STEM literacy and with it the ability to compete in the new economy." (Tsupros, Kohler, & Hallinen, 2009)

Currently the STEM education is considered to have the following benefits over the traditional science education:

- It encourages innovation by combining subject areas, which helps students make new connections between disciplines and sometimes helps create entirely new ones (Council on Competitiveness, 2005).
- It creates real life learning opportunities for students by promoting a learning environment for students to, not only learn 21st century skills, but also have the opportunity to create new skills (Narum, 2008).
- It bridges the four areas of science, technology, engineering, and mathematics classroom and shifts students away from learning discrete bits and pieces of phenomenon and rote procedures towards investigating and questioning the interrelated facets of the world (National Governors Association's {NGA}, 2007)

The current challenge appears to be the failure of most educators in the developing countries to realize that STEM education is more than simply a new name for the traditional approach to teaching science and mathematics (Bybee, 2010; Kaufman, Moss, &, .Osborn, 2003). Also they appear not to understand that STEM education is more than just the grafting of "technology" and "engineering" layers onto standard science and mathematics curricula. As a result, there is little thoughtfully planned and implemented STEM curriculum in secondary schools in this region (Lantz, 2009). Though a successful implementation of STEM education is related to the particular settings of the learning environment; most implementation plan of STEM education in schools found in developing countries appear to be centered on the "S and M" of STEM, and not fully on "S, T, E, and M". Engineering and technology have not received equal attention in the current version of STEM education (Hayes, 2009).

- **Disciplines of STEM Education**

As identified earlier, the acronym "STEM" stands for mathematics, science, technology, and engineering. In practice, these disciplines are distinguished as follows:

- **Science** stands for a discipline that develops students' ability to use scientific knowledge (in physics, chemistry, biological sciences, and earth/space sciences) and processes not only to understand the natural world, but also to participate in decisions of matters that are shaped by science in their daily lives. Such areas include: science and health, science and environment, and science and technology.
- **Technology** is discipline that develops students' ability to use, manage, understand, and assess science. It provide students with an opportunity to understand how new technologies are developed, and provides skills to analyze how new technologies affect their lives, nation, and the world at large.
- **Engineering** stands for discipline that develops students' understanding of how technologies are developed via engineering designing process. Engineering provides the students with an opportunity to integrate multiple subjects' knowledge, making difficult concepts relevant and tangible to their lives. Engineering also provides students with skills to systematically and creatively apply scientific and mathematical basics to produce designs, or manufacture an operational and efficient economical structures, machines, processes, and systems.
- **Mathematics** is a discipline that develops students' ability to analyze, reason, and communicate ideas effectively as they pose, formulate, solve, and interpret solutions to mathematical problems in a variety of situations.

In the realm of secondary education in developing countries, STEM typically refers to the study related to aforementioned disciplines. However, each of these disciplines may include instruction of several subject areas. The following table outlines common STEM subjects in secondary education.

Table 1: STEM Subjects in Secondary School Education

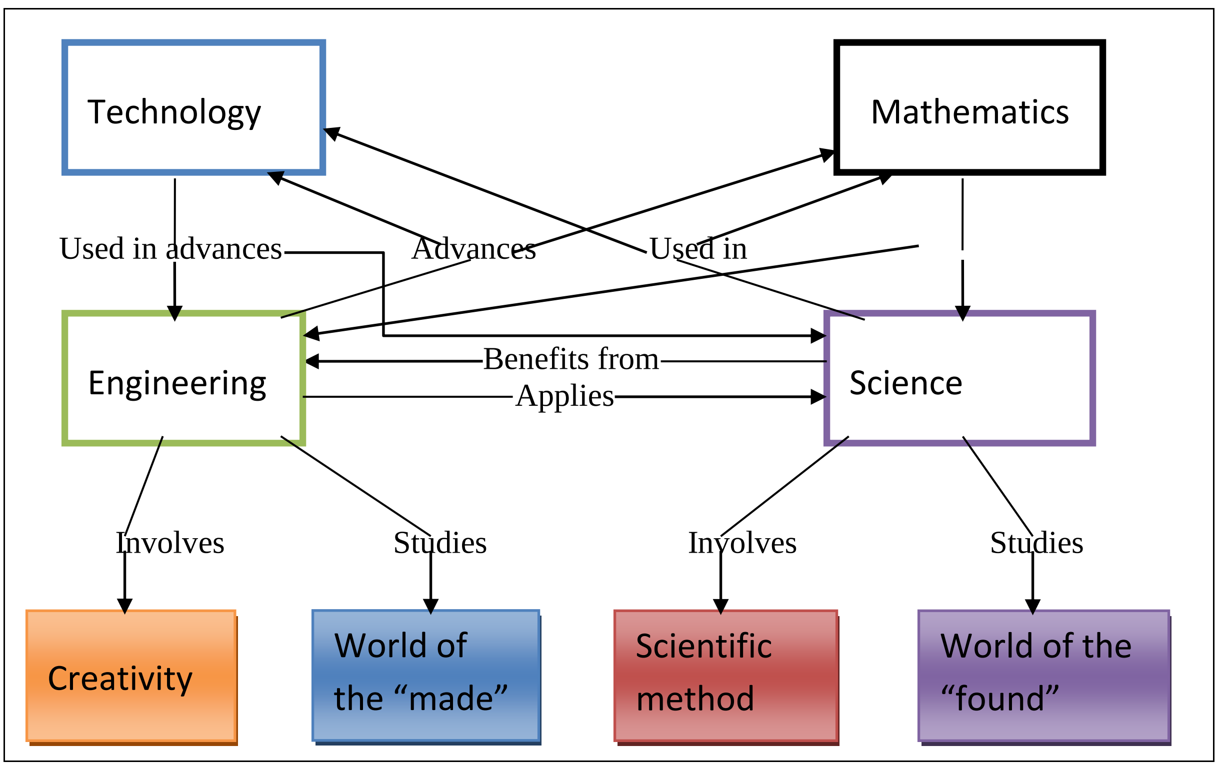
Mathematics	**Science**
Basic mathematics Basic applied mathematics (BAM) Advanced mathematics Statistics	Biology Physics Chemistry
Engineering	**Technology**
Chemical Engineering Civil Engineering Computer Engineering Electrical/Electronic Engineering General Engineering Mechanical Engineering	Computer education Technology education Informatics Information and computer Technology

Source: Modified from STEM connector (2011)

- **Relationship of the STEM Disciplines**

Proponents of STEM education are increasingly advocating the interrelated nature of all the STEM subjects and the necessity of implementing an interdisciplinary approach rather than treating the individual subjects as "silos." The following figure demonstrates this concept by illustrating some of the connections between the subjects.

Figure 1: Interrelationship between STEM disciplines



Source: A figure adopted from Thornburg (2008).

This brief analysis of interrelationships among the four STEM disciplines reveals that all the four STEM disciplines reinforce each other in support of the overall growth of each topic. Figure 1 shows that there is an ongoing expansion of knowledge that can be applied to solve ever more challenging problems in STEM. The message conveyed by this relationship is that no one of these subjects can accomplish the goals of STEM education by itself. For example, scientific advancement is not possible without engineering to produce new technologies, and the expansion of mathematical knowledge. This example brings the discussion to the conclusion that, the four disciplines of STEM education are highly interrelated, and it is important that these relationships are understood by students.

4. Goals of Effective STEM Education

The modern society is increasingly facing decisions related to STEM education, from understanding a medical diagnosis to weighing competing claims about the environment (Sorenson, 2010; Thornburg, 2008). It is from this major challenge that STEM education is organized to achieve a number of goals which capture the breadth of the purposes for STEM education and reflect the types of intellectual capital needed for the nation's growth and development in an increasingly science- and technology-driven world(PCAST, 2012). These goals are summarized in Table 2 that follows.

Table 2: Goals of STEM Education

Expanding the number of students taking STEM and broadening the participation of women and minorities in the fields STEM	**Expanding the STEM-capable workforce**
Given the changing demographics in the recent era and the need to produce more STEM-career prepared students, this goals seeks to increase the participation of students who desire to pursue advanced degrees and careers in STEM fields and broaden the participation of underrepresented groups in the sciences.	This goal seeks not only to prepare students for advanced degrees, but also for STEM-related careers, such as medical assistants and computer technicians. This is important for developing an ability of STEM education to produce the next generation of scientists, engineers, and innovators.
Closing the achievement and participation gap	**Ensuring a STEM-capable citizenry**
This goal aims to increase women and minority participation and interest in STEM fields in order to tap into the country's full potential.	This goal seeks to cultivate a citizenry that has "the knowledge, conceptual understandings, and critical-thinking skills that come from studying STEM subjects." This is important even for those who never directly enter a STEM -related career.
Building a STEM-proficient workforce.	**Cultivating future STEM experts**
This goal seeks to adequately prepare a sufficient number of workers for job openings in STEM -related careers which are expected to increase in coming years.	This goal aims to educate the best STEM experts in the world because their role to contribute "in economic growth, technological progress, in understanding of ourselves and the universe, and in the reduction of hunger, disease, and poverty
Increasing STEM literacy for all students	
This goal seeks to increase STEM literacy for all students including those who do not pursue STEM-related careers or additional study in the STEM disciplines**.** This is necessary because the challenges of the science- and technology-driven 21st century increasingly dictates that everyone have knowledge and understanding of STEM concepts for personal decision making, participation in civic and cultural affairs, and economic productivity.	

These seven goals are not mutually exclusive because they are broad long-term goals for STEM education all over the world. Inside these broad goals there are other numerous intermediate goals encompassed in them. Among others, the intermediate goals include learning STEM content and practices, developing positive dispositions toward STEM, and preparing students to be lifelong learners (Tsupros, Kohler, &Hallinen, 2009).

5. Threats for Successful Implementation of STEM Education in Schools

It is widely acknowledged from the famous European and global studies such as TIMMS, ROSE, Eurostat and PISA that many countries in the world are confronted by several issues in STEM education (Sturman, Burge, Cook& Weaving, 2012). These issues are particularly acute in developing countries. Some of these problems include:

- **Negative Perception towards STEM Education**

Inaccurate stereotypes exist around STEM education and its role in society in two ways: A stereotype related to poor perception of STEM whereby STEM is not perceived as a voyage of discovery, but rather as a dry, fact-based subject; and, the stereotype related to poor perception of gender and minority participation in STEMeducation (Hanover Research, 2011). This situation presents a need for not onlyensuring that diverse populations understand the role of STEM in their day to day lives but also STEM pioneers, educators and industry players to look for appropriate ways to address the stereotypes around STEM education and careers.

- **Lack of Policy Connectivity**

Significant disconnects exist between government policies and practice and business and industry (Institute for Higher Education Policy, 2007). Most government's policies seem to emphasize STEMeducation as a political priority but it is not usually backed up with investment at sufficiently early levels of education (i.e. funding usually focuses on university level research).Industries and business sectors seem to have varied and non-systemic efforts towards improving STEM education. Severe budget cuts at both public and private schools by the central governments remain to be a critical challenge, a situation which has led to not only a failure to run STEM programs in schools, but also failure to support students who chose some disciplines of STEM for their future careers.

- **Lack of Inspiration**

Widespread and low engagement and pursuit of STEM careers among young people, a situation that occurs as a result of negative experience of STEMat school, where young people often find STEM subjects difficult and boring (Wilson, 2011). Most science classes in developing countries have been unsuccessful to inspire students in choosing STEM education and related fields as their future career and that they have led to students' failure to find that STEM resonates with their self-perception and expectations. A challenge has therefore been on how STEM teaching and learning can be reformed to enhance engagement and uptake of STEM studies, at national and international level (Bybee, 2010). This goes hand in hand with addressing the need for alternate pathways for students who don't want to become scientists, but still need to be STEM-literate.

- **Poor up-to-date Educator Support**

Lack of relevant support and training for teachers particularly in terms of staying up to date with current scientific theories and discoveries, and knowledge of what the industry actually does, seem to be a disturbing challenge for most countries. Teachers have remained unaware of new developments in STEM in terms of knowledge, and methodologies for teaching STEM fields. Worse enough teachers at lower levels of education seem to feel uncomfortable tackling STEM related topics because STEMis rarely their field of specialization.

- **Poor Methods for Spotting Talents in STEM**

Most education systems in developing countries have poor methods for identifying and developing talents in STEM (Tsupros, Kohler, & Hallinen, 2009). As a result many students appear to be left behind, especially the talented and potentially eager students who usually do not have access to formal schooling in STEM and thus becoming so difficult for these students to develop their potentials. This situation presents a challenge offinding out how students with potential talents and interest in STEM can best be early identified and supported to fully realize their career dreams in STEM.

- **Poor Partnership Patterns in Improving STEM Education**

This situation describes a problem of poor partnership among stakeholders (informal and formal education, industry, policy makers, and associations) in tackling STEM related challenges in a more holistic and unified manner. Consequently this situation appears to weaken the efforts to successful implement STEM education in schools.

- **Imbalance of the Coverage of STEM Areas in Most School Curricula**

Despite the fact that there is a bulk research and data relating to mathematics and science education in African secondary schools; research in technology and engineering education is less mature because these subject are not commonly taught in secondary education (National Research Council, 2007). This is not to say technology and engineering education is not important at this discourse but these two disciplines appear to be not slotted in most African school curricula, a situation that makes the existing education systems fail to present STEM education in more concrete and relevant ways.

- **Poor Impact of the STEM Education in School**

Research evidence reveals that millions of children continue to pass through public schools without STEM education skills (Bybee, 2010). This has been evident in long-term measurement and evaluations such as national test scores and graduation rates thatshow to have remained flat despite significant increases in government spending for some countries.This situation presents a need to look at how the four disciplines of STEM are organized and presented in schools.

- **Declining Performance of Students from Developing Countries in STEM Compared to Students in other Countries**

The Trends in International Mathematics and Science Study (TIMSS) report revealed that students in a number of developed countries and economic competitors were by far outperforming students from developing countries in science (Sturman, Burge, Cook, &., Weaving, 2012).This report also describes evidence of poor performance in innovation-based competitiveness in terms of: percentage of young adults who have graduated from high school in science, science literacy among top students, and mathematics literacy among top students.

- **Declining Number of College Students in STEM Studies and Related Careers**

There is a rising concern about the decline of number of college students earning degrees in STEM fields and the population of the workforce prepared for science, technology, engineering, and math professions (Institute for Higher Education Policy, 2007). This situation goes in contrary to the growing number of jobs in STEM fields.Consequently the situation has led to the declining economic and security power as result of poor scientific power and inability to produce STEM-educated workforces who are likely to help in produce new and innovative technologies that will expand and create new markets and add more jobs.The development of this paper partly aims at addressing some of these issues,with an aspiration to provide a strategic framework for enhancing STEM education in schools.

6. Perspectives towards Successful Implementation of STEM

Successful implementation of STEM education appears to be surrounded by several beliefs which are regarded as important viewpoints indetermining the degree of achievement of the desire to provide effective STEM education. These beliefs towards successful implementation of STEM education can be discussed in three major areas of concern including: Support structures, professional development/teacher recruitment, and assessment practices (Noha, 2013; President’s Council of Advisors on Science and Technology {PCAST}, 2010).

- **Students' Outcome Based Perspective**

The students' outcomes are identified as crucial criteria for determining success of schools in STEM education in that they are widely available and used for ascertaining accountability, efficiency of instruction, and achievement of courses' objectives (NGA, 2007).Despite these benefits student outcomes appear not to be capable of telling the wholestory that shapes the learning achievements (success). For example it seems difficult to measure interest, motivation, and creativity in STEM education by just looking at the outcomes.This situation requires an involvement of more evaluation plan to ascertain success in STEM. This could include the measuring an ability of a learner to demonstrate certain skills acquired after instruction and assessing the participation of students in after schools programs, the story that could tell about students' engagement in STEM.

- **Perspective based on STEM School Types**

Though STEM education is virtually offered in every schools**,** National Research Council (2011) identifies four broad categories of STEM-focused schools that appear to have not only special emphasis in STEM but also are potential to meet the overarching goals for STEM education: selective schools, inclusive schools, and schools with STEM-focused career and technical education (CTE).

i. **Selective STEM Schools** tend to be focused around one or more STEM disciplines and have selective admissions criteria with highly talented and motivated students, expert teachers, and advanced curricula. They can be state residential schools, stand-alone schools, schools-within-a-school or regional centers with half-day courses. In Tanzania we had this type of schools nicknamed "schools for children with special talents". Though there is no enough research to support the effectiveness of this category of schools, the few evidence available show a range promising contribution towards meeting the target to successfully provide quality STEM.

ii. **Inclusive STEM Schools** are similar to selective STEM schools but have no selective admissions criteria, thereby serving a broader population. They can also be state residential schools, stand-alone schools, schools-within-a-school or regional centers with half-day courses. Many work under the auspices that ''math and science competencies can be developed, and that students from traditionally underrepresented subpopulations need access to opportunities to develop these competencies to become full participants in areas of economic growth and prosperity.'' These are similar to traditional schools in Tanzania. The literature recognizes the contribution of comprehensive schools in STEM education as educating the vast majority of the nation's students—including many talented and aspiring scientists, mathematicians, and engineers who might not have access to selective or inclusive STEM focused schools.

iii. **Schools with STEM-Focused Career and Technical Education (CTE).**These are schools that allow students to exploreSTEM-related career options by learning practical applications ofSTEM subject areas and are intended ''to prepare students for STEM-related careers, oftenwith the broader goal of increasing engagement to prevent students from dropping out of school.Similar to schools categories A and B above, They can be state residential schools, stand-alone schools, schools-within-a-school or regional centers with half-day courses. Many CTE programs and schools are highly regarded, but research gaps exist on their effectiveness.

iv. **Traditional Schools**

In this category STEM education is offered in comprehensive schools that are not STEM focused. The majority of these schools are traditional schools, and many of these schools do an excellent job at STEM education as they offer different programs including STEM education. Many STEM-related subjects are available to junior and high schools and some schools excel even without special programs of STEM.

- **Instruction Focused STEM**

In improving the STEM education in schools the instruction has been considered as one of major criteria to be used in judging the successful implementation of STEM education. The research evidence has shown that for a school to be successful in providing effective STEM education, it needs an instruction that captures students' interest and involves them in STEM practices (Wilson, 2011). Imperative to instruction there is a need for: Supportive school conditions for effective STEM instruction; supportive system of assessment and accountability; coherent set of standards and curriculum; teachers with high capacity to teaching their discipline; adequate instruction time; and equal access to high-quality STEM learning opportunities (National Research Council. (2007).

7. Interventions for Successful Implementation of STEM

The research establishes several promising interventions for successful implementation of effective STEM education (Morrison, & Bartlett, 2009; Narum, 2008; PCAST, 2010). These interventions can be categorized into three major groups: interventions at a practice level (i.e. school based interventions); Interventions at a policy level (i.e. Policy focused interventions); and partnership based.

- **Schools based Interventions**

  - **Setting a high Priority to Establish all the three Models of STEM-Focused Schools**

as discussed earlier in this study so as to meet the various targets for STEM education. However it should be understood that each type of these schools comes with its own set of strengths and limitations (Subotnik, Tai, & Almarode, 2011). The research base seem not to support an existence of one school type over another or treating a particular type of school as an indicator of STEM excellence by itself.

  - **Adequate Instructional Time**

The decrease in time for science education is a particular concern because some research suggests that interest in science careers may develop if there is adequate instructional time (Wilson, 2011). Effective instruction capitalizes on students' early interest and experiences, identifies and builds on what they know, and provides them with experiences to engage them in the practices of science and sustain their interest (National Research Council, 2007). Therefore devoting adequate instructional time and resources to STEM education in early grade of schooling is not only important but also necessary for building a strong foundation that can stimulate students' interest in taking more science courses in middle school and high school and, possibly, in pursuing STEM disciplines and careers.

  - **Quality Learning Support Structures**

Research studies confirm that academic support structures for students have a significant impact towards increasing students' engagement, interests in STEM studies (National Research Council, 2007). Such support structures include personalized teaching, mentoring, STEM clubs activities, counseling and guidance.Therefore for successful implementation of STEM teachers need to build a classroom culture and supportive learning environment, in which students are motivated to figure out rather than learning what they are told, in which student expect some responsibility for this work of figuring out rather than waiting for answers, and where studentsare guided to learn individually or learn with their peers.

  - **Setting a Coherent Set of Standards and Curriculum**

Successful STEM education can also be judged based on the coherence of its standards and curriculum.Success in STEM is likely to be achieved when curriculum is rigorously focused on the most important topics in each disciplineand its content articulated as a sequence of topics and performances. Research evidence also suggests that adopting rigorous standards and aligning curriculum and assessments to those standards can lead to gains in student achievement (Morrison & Bartlett, 2009). As such there appears to be a close relationship between standards and students' achievement; and that success in STEM is possible when there is effective content coverage, effective instruction, and presence of coherent, focused, and rigorous standards.

  - **Enhancement of the Capacity of Teachers for STEM Education**

To meet the demands for effective STEM education, teachers need content knowledge and expertise in areas of STEM (Gamoran, Anderson, Quiroz, Secada, Williams, &, Ashman, 2003). It appears unfortunate that many science and mathematics teachers seem to underprepared for these demands; the professional development programs for teachers in STEM have often been short, fragmented, ineffective, and not designed to address the specific need of individual teachers (Wilson, 2011). This need presents a challenge of redefining teacher development programs towards a continuum improvement fashion that begins from initial preparation to induction into the practice of teaching.To achieve success in STEM education through teacher education there is a need for refashioning of teacher education development programs towards the following: Developing teachers' capabilities and knowledge to teach content and subject matter; addressing teachers' classroom work and the problems they encounter in their school settings, and providing multiple and sustained opportunities for teacher learning over a substantial time interval.

- **Supportive Learning Assessment System**

A successful STEM education system requires a supportive formative and summative assessment procedurethat can enable schools to determine whether the curriculum is having the intended impact on student outcomes or not. Studies by Minstrel, Anderson, and Li, (2011) and Wilson (2011) identify that a supportive assessment procedure takes a form of standards-based science assessment approach, whereby curriculum, instruction, and assessment are all aligned with the standards; target the same goals for learning, and work together to support students' developing science literacy (Wilson, 2013). Basically a supportive assessment system appear to have the following benefits: Enables all stakeholders to share a vision and goals for science education, the purposes and uses of assessment, and identifies what constitutes competent performance; takes into account how students' science understanding, abilities, develops over time; and focuses on teacher practices as well as on student outcomes. Despite such gains from a supportive assessment system, it appears that most of the current assessments practices limit teachers' ability to teach in ways that are known to promote quality STEM education.

- **Policy Based Interventions**
  - **Equal access to High-Quality STEM Learning Opportunities**

Many factors contribute to students having unequal access to quality STEM education (OECD, 2006; Robelen, 2011). These factors include classroom-level factors such as: Unequal access to adequate laboratory facilities, resources, and supplies; disparities in access to well-trained or credentialed teachers, less rigorous STEM courses; and poor methods for tracking talents in STEM at early grades. All these inequalities happen to contribute to gaps in achievement for underrepresented groups. Such a situation calls for policies to ensure that well-prepared teachers are available so that schools can be able to address the imbalance in students' access to quality STEM education and related services.

- **Differential Pay for STEM Teachers**

This kind of initiative is important in that it allows STEM teachers to receive higher salaries than teachers of other subjects. This is particularly necessary since those who are qualified to be STEM teachers seem to be in greater demand in professional fields beyond education than other teachers. This can be implemented in various ways including performance-based pay, a payment practice which creates new incentives to promote excellence in teaching and students' learning.

- **Opportunities to Increase the STEM Teaching Force**

This is an opportunity for state policies to create an avenue for opening up new pathways for qualified professionals to become school STEM teachers by enacting alternative teacher certification programs, which would allow qualified professionals to train to become school teachers without completing traditional teacher certification requirements. This process would particularly be helpful for increasing the pool of effective STEM teachers (Kaufman, Moss, &, Osborn, 2003; National Research Council, 2007). Therefore for a successful STEM education to happen there needs to be some concerted efforts for a coherent, focused, and sustained investment on STEM education (Allens worth, 2011). This is necessary for building motivation, retention of STEM teachers in teaching, developing morale to teach, attracting youths in STEM teaching profession. Teachers in STEM should be provided with options to pursue professional learning that addresses their professional needs through a variety of mechanisms, including peer-to-peer collaboration, professional learning communities, and outreach with universities and other organizations.

- **Elevation of Status of STEM**

Improving the status of STEM education involves an operation of polices to elevate the ignored aspects of STEM (such as technology and engineering education)to the same level of importance as science and mathematics and develop effective systems of assessment (Institute for Higher Education Policy, 2007; Kuenzi, 2008). Such policy operations in STEM education are not currently available in schools (Salinger & Zuga, 2009). This situation calls for the need of states and national organizations to develop effective systems of assessment that are aligned with the next generation of science standards and that emphasize science practices rather than mere factual recall.

- **Participation Based Interventions**
- **Involvement of Private Sectors**

The Wider participation from all stakeholders, including: *Schools* (school leadership, teachers, lab assistants, careers advisors);Universities(teacher training faculties, science faculties); Ministries of education (policy makers, curriculum developers, inspectorates, local education authorities); Associations (teacher associations, science associations); Industry (STEM companies, school supplier {of STEM equipment and resources}, publishers, school media);Science centers and museums (school outreach staff, science communicators); Media (science communicators, science press, TV and internet); Associations (science fairs and festivals, science associations, youth associations, community groups); Industry (STEM companies); and Government (local authorities, ministries of science, technology and research).

These entire stakeholders when involved effectively can support STEM education by implementing partnerships with schools in many ways including funding and advisory support (Partnership for 21st Century Skills, 2011). The purpose of multi stakeholder involvement is built on the need to make the responsibility of improving STEM education a shared responsibility. Integration of all levels of STEM implementation from formal to informal education, and from student to policy maker needs to be created, so that the private sectors do not need to wait for state government permission before they can chip in to address the STEM education crisis.

- **Strengthening Partnership Between Schools and External Organizations**

The partnerships between schools and outside groups provide an important influence towards successful implementation of STEM strategies (Partnership for 21st Century Skills, 2011; Bybee, 2010). This intervention happens to help to enhancing the capacity to offer quality STEM education and learning experiences. This is because what determines the success of whatever initiative in STEM education is not what schools tackle individually (e.g., professional development, curriculum, or afterschool programs), but whether there is marriage of interests between the school and the community.

- **Adapting a Systemic Approach towards Effective STEM Education**

Currently, each type of stakeholder, although active, seems to develop some responses to the challenges, but often in isolation, or in small groups that are unable to stimulate the system-wide change required. This situation brings a need for solid, sustainable and hence long-term multi- stakeholder partnerships bringing together diverse actors able to tackle the inter-related angles of the STEM education challenges.

8. Conclusion

With regard to the broad question of how to make STEM education successfully implemented in schools, there are promising approaches that range from policy level to individual involvement in making such dream a reality. However neither the current research findings nor the ones to come can provide a universal framework for successful implementation of STEM education in schools. There will still be gaps in the knowledge base. One possible reason for that is the significant diversity in STEM education, even within a given country. However for thoughtful pragmatic approach to achieving this dream there is one area to consider addressing. This includes the context in which schools are operating. This area is important in that: It determines the resources that are available to support the school; it provides direct support and experience for STEM students; and influences policies that shape the school operations, such as district laws that do or do not allow school leaders and teachers' flexibility for them to be effective.

The vision to successfully implement STEM education has great promise, but also great demands. The desire requires sufficient investment of time, resources, and aligning different parts of the system to be focused towards achieving the desire. There are certainly political and pragmatic challenges facing these efforts. But our communities of science educators, researchers, and policy makers have a responsibility to continue reminding about the need to improve STEM education in school through research and publication in the area of STEM education.

Areas for Future Research

A number of research gaps are identified throughout the paper. Much research is underway, but not yet conclusive. In view what has been covered in this paper, there is a need for the following to be addressed:

- Broadening research on measuring success beyond student test scores, graduation rates, the data which is important for developing a more comprehensive analysis of the implementation of STEM education in schools.

References

Allensworth, E.M. (2011). Conditions to support successful teaching: School climate and organization. Presentation at the workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education, National Research Council, Washington, DC, May 10-12, 2011.

Bybee, R. (2010). Advancing STEM education: A 2020 vision. Technology and Engineering Teacher, 70(1), 30-35.

Council on Competitiveness (2005). Innovate America: National Innovation Initiative Summit and Report. Washington, DC: Author. Retrieved on Nov 2015, from (http://www.compete.org/images/uploads/File/PDFFiles/NII_Innovate_America.pdf)

Council on Competitiveness, (2005). Innovate America: National Innovation Initiative Summit and Report. Washington, DC: Author. Retrieved March 13, 2014, from (http://www.compete.org/images/uploads/File/PDFFiles/ NII_Innovate_America.pdf)

Gamoran, A., Anderson, C.W., Quiroz, P.A., Secada, W.G., Williams, T., and Ashman, S. (2003). Transforming Teaching in Math and Science: How Schools and Districts can Support Change. New York: Teachers College Press.

Hanover Research. (2011).K-12 STEM Education Overview. Hanover Research-District Administration Practice. NW: Washington

Institute for Higher Education Policy. (2007). Diversifying the STEM Pipeline: Recommendations from the Model Replication Institutions Program. Washington DC: Institute for Higher Education Policy.

Kaufman, D., D. Moss, and T. Osborn (Eds), (2003). Beyond the Boundaries: A Trans-Disciplinary Approach to Learning and Teaching. Praeger, Westport, Connecticut.

Kuenzi, J.J (2008). Science, Technology, Engineering, and Mathematics (STEM) Education: Background, Federal Policy, and Legislative Action.CRS Report for Congress, Washington: DC

Lee, O. (2011). Effective STEM education strategies for diverse and underserved learners.Paper Prepared for the Workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education, National Research Council, Washington, DC

Lip, D. &, McNeill, J. B. (2009). A New Approach to Improving Science, Technology, Engineering, and Math Education. Heritage Foundation, Backgrounder, No. 2259.

Morrison, J. & Bartlett, B. (2009). STEM as a Curriculum: An Experimental Approach. Retrieved on March 13, 2014, from from(http://www.labaids.com/docs/stem/EdWeekArticleSTEM.pdf)

Means, B., and Penuel, W.R. (2005). Scaling up technology-based educational innovations. In C. Dede, J.P. Honan, and L.C. Peters (Eds.), Scaling Up Technology-Based Educational Innovations. San Francisco: Jossey-Bass.

Minstrell, J., Anderson, R., and Li, M. (2011). Building on learner thinking: A framework for assessment in instruction. Paper Prepared for the Workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education, National Research Council, Washington, DC.

National Research Council. (2007). Taking Science to School: Learning and Teaching Science in

National Research Council. (2011). Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics. Committee on Highly Successful Schools or Programs for K-12 STEM Education, Board on Science Education and Board on

National Research Council (NRC). (2011). Successful STEM education: A workshop Summary. Alexandra Beatty, Rapporteur. Committee on Highly Successful Schools or Programs for K–12 STEM Education, Board on Science Education and Board on Testing and Assessment. Washington, DC: The National Academies Press.Grades K-8. Washington, DC: The National Academies Press

Narum, J. L. (2008). Promising Practices in Undergraduate STEM Education.Retrieved March 14, 2014, from (http://www7.nationalacademies.org/bose /Narum_CommissionedPaper.pdf)

NGA, (2007). Promoting STEM Education: A Communications Tool Kit. Retrieved from National Governor's Association website, March 15, 2014 from (http://www.nga.org/files/live/sites/NGA/files/pdf/0804STEAMTOOLKIT.PDF)

Noha, A. A. (2013). The Egyptian STEM schools, a national project that is leading Egypt into a strong and vibrant educational and economic reform.Paper Presented at the Annual Meeting of the 57th AnnualConference of the Comparative and International Education Society, HiltonRiverside Hotel, New Orleans, LA, Mar 10, 2013.

Organization for Economic Co-operation and Development –Global Science Forum-OECD-GSF.(2006). Evolution of Student Interest in Science and Technology Studies Policy Report. OECD: Paris.

Partnership for 21st Century Skills. (2011). Framework for 21st Century Learning. Retrieved on 1st February, 2016 from Partnership for 21stCentury Skills: (http://p21.org/overview/skills-framework)

PCAST (President's Council of Advisors on Science and Technology). (2010). Prepare and Inspire: K-12 Education in STEM(science, technology, engineering and math) for America's Future. Retrieved November 13, 2010, from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stemed-report.pdf

Robelen, E. (2011). New STEM Schools Target Underrepresented Groups. Education Week.Retrieved March 15, 2014 from (http://www.edweek.org/ew/articles/2011/09/14/03stem_ep.h31.html?r=148195741)

Salinger, G. & Zuga, K. (2009). Background and history of the STEM movement. In ITEEA (Ed.), The Overlooked STEM Imperatives: Technology and Engineering (pp. 4-9). Reston, VA: ITEEA.

Sanders, M. (2009). STEM, STEM Education, STEMmania, Technology Teacher, 68 (4), 20-26.

Schmidt, W.H. (2011). STEM reform: Which way to go?Paper presented at the National Research Council Workshop on Successful STEM Education in K-12 Schools. Available at:http://www7.nationalacademies.org/bose/STEM_Schools_Workshop_Paper_Schmidt.pdf.

Smith, M.S., and O'Day, J.A. (1991). Putting the Pieces Together: Systemic School Reform. CPRE Policy Brief, RB-06-4/91. New Brunswick, NJ: Consortium for Policy Research in Education.

Sorenson, Bernie (2010). Alaska STEM: Education and the Economy. Report on the Need for Spring Board program of theJuneau Economic Development

Stein, M.K., and Kaufman, J.H. (2010). Selecting and supporting the use of mathematics curricula at scale. American Educational Research Journal, 47(3), 663-693.

Sturman, L., Burge, B., Cook, R., and Weaving, H. (2012). TIMSS 2011: Mathematics and Science Achievement in England. Slough: NFER. Accessed from www.nfer.ac.uk/timss on 22nd January, 2016

Subotnik, R.F., Tai, R.H., and Almarode, J. (2011). Study of the impact of selective SMT high schools: Reflections on learners gifted and motivated in science and mathematics.Paper prepared for the workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education, National Research Council, Washington, DC,

The Oregon STEM Education Initiative (2011). Retrieved March 15, 2014 From (http://www.ode.state.or.us/wma/teachlearn/cte/cte_updates/cte_upstemeducation-Initiative-draft-for-public-review-11-3-11--(2).doc)

Thornburg, D. (2008). Why STEM Topics are interrelated: The Importance of Interdisciplinary Studies in K-12 Education. The Thornburg Center for Space Exploration, p. 3. http://www.tcsek12.org/pages/stem.pdf.

Tsupros, N., Kohler, R., &Hallinen, J. (2009). STEM Education: Project to Identify the Missing Components. Washington: Intermediate Unit 1: Center for STEM Education.

West, M. (2012) .Stem Education and theWorkplace. Canberra, Office of the Chief Scientist.

Wilson, S.M. (2013). Professional development for science teachers. Science,340(6130),310-313.

Wilson, S. (2011). Effective STEM Teacher Preparation, Induction, and Professional Development. Washington DC: National Academies Press.

Wilson, S.M. (2011).Effective STEM Teacher Preparation, Instruction, and Professional Development. Paper prepared for the workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education. National Research Council, Washington: DC