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Barriers to Successful Implementation of STEM Education

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Abstract

The implementation of STEM education in schools across the globe is to prepare the future workforce with strong scientific and mathematical backgrounds to enhance skills development across STEM disciplines. However, for STEM education to achieve its goals and objectives, addressing the barriers to STEM education should start by fixing the problems at the elementary, junior and senior high school levels; the grassroots and potential feeders to colleges and universities. Since many nations including the United States of America is in dire need of the workforce with adequate preparation in science and mathematics to help address the nation's economy that is in shambles, the barriers to its successful implementation should be identified and addressed. In this paper, (a) the definition of STEM education and (b) some barriers to successful implementation of STEM education are discussed and elaborated.

Keywords: *STEM education, meta-discipline, discipline-specific*

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Introduction

The essence of STEM education is to prepare the 21st century workforce with STEM education and its related activities so that students can take what they learn in the classroom/ laboratory and apply it to their future jobs in the real world. Educators, industry and the business community should work as a team to develop curricula that will enhance this expectation. More important, in addition to curricula development, this collaboration between schools and professionals in the industry should include internships, mentoring, the delivery of hands-on activities in the classroom to introduce the students to careers across STEM fields and fundamental skills.

What is STEM Education?

STEM education is a “meta-discipline” and this means the “creation of a discipline based on the integration of other disciplinary knowledge into a new ‘whole’ rather than in bits and pieces. It is an interdisciplinary approach (Morrison, 2008; Tsupros 2008) to learning by integrating the four disciplines into one cohesive teaching and learning paradigm. This integration that is aimed at the removal of the traditional barriers erected between the four disciplines is now branded as STEM (Morrison, 2008). According to Tsupros (2008), “STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts 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, 2009).”

According to Brown, Brown, Reardon & Merrill (2011), STEM education has been defined as “a standards-based, meta-discipline residing at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline-specific content is not divided, but addressed and treated as one lively, fluid study.”

Barriers to successful implementation of STEM education

There is growing concern that the United States is not preparing a sufficient number of students, teachers, and professionals in the areas of science, technology, engineering, and mathematics (STEM). Although the most recent National Assessment of Educational Progress (NAEP) results show improvement in U.S. pupils’ knowledge of math and science, the large majority of students still fail to reach adequate levels of proficiency. Implementation of STEM education to prepare the 21st century workforce will contribute to the improvement of the crumbled economic situations if well harnessed. For STEM education initiative to be adopted by any society must be understood to avoid the risk of compounding its societal problems. In addition, STEM educator should assume the new role of a facilitator in the classroom or laboratory. As such, it is necessary to address and reduce the barriers to successful implementation of STEM education. The following are some of the identified barriers to STEM education that are attributable to the lost of interest in STEM disciplines by students who would have become future scientists, engineers, and technologists: Poor preparation and shortage in supply of qualified STEM teachers, lack of investment in teachers professional development, and lack of research collaboration across STEM fields.

1. Poor preparation and shortage in supply of qualified STEM teachers

The quality of teacher preparation is crucial to helping students reach higher academic standards. Unfortunately, many classrooms today are filled with under-prepared individuals because they have received poor quality training or none at all. Many scholars have conducted research over the past two decades with regard to the relationship between poor preparation of teachers in mathematics and science and student achievement (Rule & Hallagan, 2006; Hibpshman, 2007). This work resulted from two events, shortage of literature to identify reliable predictors of student achievement based on global measures of teacher qualifications (Hill, Bowan & Ball, 2005) and about the components of knowledge necessary for teachers to perform successfully (Shulman, 1986). However, it became known to researchers that what was known about teacher competencies was insufficient to explain student achievement (Hibpshman, 2007). This finding have led various organizations, such as the National Council of Teachers of Mathematics (NCTM), the National Research Council (NRC), the National Science Teachers’ Association, and the Conference Board of the Mathematical Sciences (CBMS) to publish guidelines to guide the preparation of programs and certification of both elementary teachers and secondary STEM teachers.

The 2007 Academic Competitiveness Council (ACC) report indicate that “postsecondary degrees in math and physical science have steadily decreased in recent decades as a proportion of all

STEM degrees awarded. Although degrees in some STEM fields (particularly biology and computer science) have increased in recent decades, the overall proportion of STEM degrees awarded in the United States has historically remained at about 17% of all postsecondary degrees awarded.” In the study conducted by Seymour & Hewitt (1997), 74% of students successfully graduating from their STEM programs identify poor instruction as a major obstacle. According to the Monk (1994) Longitudinal Survey of American Youth found that how much a teacher knows about his subject has a positive effect on students’ learning. More important, this study found that an increase of one mathematics course for a teacher with modest mathematical training was associated with a 1.2% increase in student achievement for high school juniors but that the addition of further courses beyond five had a diminishing effect. In addition, the author stated that the number of courses in a teacher’s background had a positive effect on students’ achievement in AP courses but not in remedial courses.

Posamentier & Maeroff (2011) noted that who teaches in STEM programs matters. The authors asserted that a typical elementary school teacher that has minimal preparation in any STEM field tends to lack confidence in his/her knowledge of the subject and may bequeath this anxiety to students. The study conducted by Goldhaber & Brewer (1998) found that earning a subject-specific degree had a positive effect on student achievement in both mathematics and science. According to the recent NRC report on teacher preparation concluded that too little information is known about the preparation of Science teachers, citing a 2003 survey showing that 28 percent of the U.S. public school teachers who are teaching science in grades 7-12 lack a minor or major in the sciences or science education (Ingersoll & Perda, 2010, p. 146). In an earlier study by these authors, a 2008 study showed that 40 percent of mathematics classes in high-poverty secondary schools were taught by out-of-field teachers, whereas 83 percent of classes are taught by teachers with mathematics or mathematics education degrees in schools that serve the fewest low-income students (Ingersoll et al, 2008).

According to the 2010 report of the President’s Council of Advisors on Science and Technology (PCAST), the turnover yearly in the STEM teaching force particularly in mathematics and science disciplines could reach 25,000. In addition, the report indicate that within the first five years of teaching, more than 40 percent of teachers decide they no longer want to teach due to lack of professional support. Since teacher turnover takes a long time, those already in classrooms must undergo a great deal of professional development. In addition, novice teachers should be educated differently to become specialists in each STEM field so as to synergize the efforts of two or more subject specialists as team pairs of teachers.

To ensure that potential STEM teacher graduate from college and have a full mastery of their teaching subjects, the curriculum should be expanded to expose them to the nitty-gritty of subject content. In addition, the standard in teaching methodology and courses such as sociology, philosophy and psychology that are relevant to the mastery of education as a program should not be lowered. According to Hibpshman (2007) & Deines (2011) state’s science standards and other STEM disciplines should be reviewed. The knowledge base for teaching to supply qualified teachers such as science standards are to be written to be ‘more cross-cutting’ and involve more ‘science reasoning’ rather than as previous stand-alone concepts (Clark et al., 2008; Aleman, 1992). The ambiguity of being controversial when it comes to standards for STEM disciplines that may lead to focusing on one particular area and forget there are other areas other than one discipline should be avoided. Board members should give “serious consideration” to adopting the national standards that would give guidance to school districts for their science and other STEM discipline curriculum choices. In addition, this process should be made transparent for getting input on the drafts of the standards. In addition, each participating state board of education should be allowed to nominate representatives of business and industry to review the drafts of the science and other STEM disciplines’ standards.

The 2010 PCAST report “Prepare and Inspire: K-12 Science, Technology, Engineering, and Math (STEM) Education for America’s Future”, indicate that many of the highest paying professions for recent college graduates are related to STEM fields. More important, most proficient STEM students in colleges are attracted to careers other than teaching. As a result, other means of attracting and retaining the best-trained STEM students to the teaching profession should be devised. For effectiveness, this strategy should be unique and differ from those required to recruit teachers in other fields.

For a pool of teachers that will be dedicated to teaching in STEM fields, being equipped with deep content knowledge in STEM and strong pedagogical skills for teaching their students are two essential attributes they should possess to be able to help students achieve deep understandings of STEM for later utilization in their lives and careers. Unfortunately, not many teachers in STEM classrooms possess these attributes. Curriculum for STEM teacher preparation should emphasize these two attributes. In addition, teachers should be motivated to participate in professional development to help them achieve deep STEM content knowledge and mastery of STEM pedagogy.

2. Lack of investment in teachers professional development

The lack of investment in the professional development of teachers for strong knowledge base has been attributed to poor student performance. As inspired teaching inspires students, new teachers need professional internships for clinical training following completion of degree. The National Council on Teacher Quality reported that all but a quarter of the student-teaching practices program in 134 educational schools earned a “week” or “poor” rating (Sawchuk, 2011). In addition, the report also contended that too many elementary-level teachers are being prepared for graduation by colleges.

More important is the need for mentoring new educator’s work by expert mentor educator to make sure they learn to teach effectively. Making the matter worse is that many school districts assign new teachers into the toughest class with no assistance during their first critical months of teaching. However, when a school district includes mentoring by an experienced teacher, opportunities to collaborate with colleagues and get assistance in managing assignments, this will allow them to learn to teach effectively.

According to Hibpshman (2007), ongoing professional development activities in mathematics and science should be extended to improve the content knowledge and skills of elementary teachers and mathematics and science teachers at the middle and high school levels. Mervis (2011), asserted that “anything that dilutes those ingredients—budget cuts, poor teacher preparation and professional development, a disregard for low-achieving students, to name three factors—will lower the chances of success.” Herrick (2011) opined that now is the time to make significant investments in science education, with long-term sustainability as the ultimate goal to ensure that teachers are well-equipped. Failure to implement this will lead to poor teaching methods and unresourcefulness which have failed to increase the curiosity and self-guided inquiries on the part of the learners (Nwanekezi et al., 2010).

3. Poor preparation and inspiration of students

The 2011 STEM Report from the Department of Commerce indicate that job opportunities in science, technology, engineering, and math fields (STEM) are increasing in America. This report state that STEM workers earn 26% more on average than their non-STEM counterparts and it provided data to support the need for a highly educated STEM workforce. However, giving the poor preparation and inspiration of students to pursue STEM programs, how will the employers be able to recruit and hire the highly skilled employees needed?

According to a new STEM study released by Microsoft and Harris Interactive, most college students studying for degrees in science, technology, engineering or math make the decision to do so in high school or before. However, only 20 percent say they feel that their education before college prepared them “extremely well” for those fields. The survey which also asked both college students pursuing STEM degrees and the parents of K-12 students about attitudes toward STEM education, also found that male and female students enter the fields for different reasons: females are more likely to want to make a difference, while males are more likely to say they’ve always enjoyed games, toys or clubs focused on the hard sciences.

The 2010 PCAST report concluded that too few U.S. students are proficient in STEM and that too few of those who are proficient pursue STEM fields. For example, of all ninth graders in the United States in 2001, only about 4 percent are predicted to earn college degrees in STEM fields by 2011. The loss of potential STEM talent begins well before high school. In both mathematics and science, the 70 percent of eighth graders who lack proficiency face a mounting barrier as they experience increased difficulty in STEM subjects due to lack of a solid foundation in basic skills such as algebra. More important is the fact that among the minority of students who are proficient in STEM in eighth grade, 60 percent decide during high school that they are not interested in these subjects and only about 40 percent actually enter STEM majors in colleges. According to the report, these two recommendations will suffice to address these challenges. On the one hand, students must be *prepared* to have a strong foundation in STEM no matter what careers they pursue. This preparation should involve building shared skills and knowledge. On the other hand, students must be *inspired* so that all are motivated to learn STEM subjects so that many of them will be excited to enter STEM fields. This will be feasible through meaningful experiences that speak to students’ particular interests and abilities.

According to Laboy-Rush (2011), “When teachers expose students early to opportunities to learn math and science in interactive environments that develop communication and collaboration skills, students are more confident and competent in these subjects. This not only makes higher education more attainable for students, but also contributes to a well-prepared society.”

4. Lack of connection with individual learners in a wide variety of ways

According to the 2008 CRS Report for Congress titled *Science, Technology, Engineering, Technology and Mathematics (STEM) Education: Background, federal policy, and legislative actions*,

“When compared to other nations, the achievement of U.S. pupils appears inconsistent with the nation’s role as a world leader in scientific innovation. For example, among the 40 countries that participated in the 2003 Program for International Student Assessment (PISA), the U.S. ranked 28th in math literacy and 24th in science literacy.”

To enhance students’ performance in STEM programs, individual learners should be connected to a wide variety of ways to improve learning in STEM fields (Darling-Hammond, 1994). Current research in project-based learning demonstrates that projects can increase student interest in STEM because they involve students in solving authentic problems, working with others, and building real solutions (Fortus, Krajcik, Dersheimer, Marx, & Mamlok-Naamand, 2005). In addition, through an integrated approach to STEM education focused on real-world, authentic problems, students learn to reflect on the problem-solving process (Aleman, 1992; Darling-Hammond, 1994; Fajemidagba et al., 2010). More important, students learn best when encouraged to construct their own knowledge of the world around them (Satchwell & Loepp, 2002). It is through integrated STEM projects that this type of learning can occur.

Some approaches to connect individual learners in a wide variety of ways are after-school programs; STEM contests, design and building; and summer programs.

After-school programs – since many learners participate in out-of-school programs and most of these programs have no particular connection to STEM, adaptation could be made possible by providing instructors in these centers with engaging materials with preparation and guidance on how to use those materials to enrich experiences in STEM.

STEM contests – is an out-of-class STEM contests that can reward creativity and problem solving. In my college, there is yearly science fair that brings students from junior and high schools together to show case their projects in this fair so as to introduce them to a community of like-minded peers. Other example of STEM contests that could be implemented to make STEM education more meaningful, challenging and interesting to students are the Siemens Competition in Math, the Intel Science Talent Search and International Science and Engineering Fair, the FIRST Robotics Competition, and more. To involve the participation of all students regardless of their social status, poor or affluent students should be equally encouraged and supported with funding for entry fees, materials, and travel expenses to participate in those programs as needed. In addition, teachers designated to engage and support these students should be adequately trained, supplied with materials, and supplemental pay.

Designing and building – which is another form of out-of-class is another program that is suitable for stimulating student’s interest in STEM program. This is an excellent opportunities for extended projects based on inquiry, construction, and discovery for learners. For example, the bridge building contest enables learners to use hands-on, inquiry-based investigations, designing and building to solve problems. In addition, student’s communication skills are developed by presenting to other class members. In addition, this is an opportunity for learners to develop technical, creative, critical thinking skills that are necessary to perform well in STEM disciplines.

Summer programs – keeps young learners occupied while learning. Funded programs by the National Science Foundation support summer programs to engage both students and teachers in STEM activities. This is an in-depth class or research project for student and teacher participation during the summer with the objective of building the interest of science-oriented high school students and professional development for the teachers.

5. Lack of support from the school system

The study published by the Education Alliance at Brown University stated that in order for growth to occur in the school systems, it is necessary that the structures and thinking on how to conduct the business of education must be altered (Unger et al., 2008). The will be harnessed when the measure of leadership is demonstrated on how well agencies connected with the goals of the districts and schools for an engaged learning environment.

It is important to ensure that education leaders are knowledgeable about STEM education so as to cultivate rich STEM learning experiences and expertise in their schools. The present economic situation that has necessitated cutting funds needed to support educational activities makes it very easy for the school system to truncate the need for STEM program. Due to this predicament, funds may not be available to secure teachers who know how to teach science and mathematics effectively, and who know and love their subject well enough to inspire their students. In a situation like this, the service of qualified volunteers could be sought among the retirees so that learners will not be at disadvantage. On the other hand, according to the 2011 National Survey on STEM Education conducted, over 400 STEM leaders responded that “*The most frequently identified funding sources were grants from private*

foundations (31.9%) and district-led initiatives (25.9%).” As such, leaders that do experience fund shortage could developed STEM alliances that rely on both public and private funding.

6. Lack of research collaboration across STEM fields

Many STEM educators have failed in their efforts to collaborate with other STEM educators that teach other STEM disciplines. This has resulted poor skill development in giving learners adequate sense of direction and purpose for effective learning and choice of career in STEM related fields. Since STEM education is an integration of many disciplines with their differences and similarities, a normal approach to teaching and learning should be devised through collaboration of the educators involved. Research collaborations through cluster concept across STEM fields for integrated curriculum will enhance connectivity and information sharing among the stake holders. Therefore, all efforts should be made to foster increase in research collaboration activities among educators and partnership with the industry personnel to bridge across the traditional approach to teaching and learning in the classroom.

Research collaboration and the cluster concept across STEM fields have evolved to synergize the “diversity” that exists across the STEM fields. Such is the opportunity to have a pool of talented professionals coming together to share knowledge, to learn from each other, understand how to integrate other disciplines effectively with theirs, to identify individual’s resourcefulness and devise a means to tap into the synergistic effort of all participants. This is will make teaching and learning, professional and skills development among scholars and students to be feasible and effective. In addition, it affords participants the opportunity to work in harmony, learn how to learn from their colleagues from other disciplines different from theirs and the industry.

7. Poor Content preparation

If the United States is to remain competitive in a global economy, the participation of American students in STEM fields must increase. ‘Preparing instructional materials is the process by which a sketchy working outline is transformed into finished learner directions or guide-sheets, instructional materials, tests, and instructor directions or guide-sheets’ (Rothwell et al., 1992, p. 207). In order to attract and retain a new generation of learners, engineering and technology curricula need to be renovated to optimize the skills that are relevant today. More important, all new teaching materials should provide clear guidelines for all anticipated work-load and classroom activities. STEM educators and students will benefit from explicit outcomes for courses, assignments, and projects. When specific and clear outcomes are identified, not only can the instructors focus their instruction on specific knowledge, but they can also link their knowledge assessment directly to the outcomes.

8. Poor Content delivery and method of assessment

Bruner (1961) postulated that the learner learns through discovery activities varied out by the child using materials and learner’s mental process. According to Onuja (1987), the method of teaching determines the amount of knowledge that learners acquires. The STEM educator as a facilitator will not only be knowledgeable in the subject but should also possess the basic and necessary skills with which to impact the knowledge of the subjects to the students and learners at all levels of learning (Nwanekezi et al., 2010). When teaching is not effective, the learners grasp little or nothing and this reflects in the future choice of career. This implies that STEM educators should endeavor to understand the available methods and teaching strategies and select from them according to the demand of the lesson at hand with attention to the diverse nature of the students in the classroom, their learning styles and abilities. It is suffice to say that in STEM education, ‘one size fit all’ approach to teaching and learning will not work.

Distinct approaches to teaching methods, content instruction, and curriculum organization come and go over the years. It is unrealistic to expect that a particular approach will be successful for all learners. This expectation only leads to disappointment and another swing of the education pendulum. Instead of an either-or mentality, many experienced teachers know that using the best of a variety of approaches benefits many learners. Instructional tools must be carefully and intentionally adapted to accommodate individual learners. Only in this way will all students have an opportunity for success (Guild, 1998).

More important, when students are engaged in STEM education, they should be made to understand how STEM are interrelated in the application of different STEM disciplines to solve problems, how the their activities are based on analysis and interpretation of evidence or prototype building. STEM education is a standard-based interdisciplinary discipline. As such, the method of assessing learning outcome should not only be based on cognitive domain. It should include affective and psychomotor domains. With this practice, learner’s basic skills would be developed and their interest in STEM subjects would be built (Nwanekezi et al., 2010).

9. Poor Condition of laboratory facilities and instructional media

According to the article published in Education Week regarding classroom management by Krueger & Whitmore (2001), the result of the five years research done by University of Wisconsin asserted that classroom is the most important area within the school where student spent most of their time and that overcrowding in classroom can make facilitation of students' activities less-effective. The study affirms that reduction of class size can result in higher achievement for children living in poverty. Therefore, the environment of the classroom/laboratory should be made conducive to learning.

As indicated by many reports, STEM education should help prepare many scientists, engineers, and technologists for the future, inadequate facilities and lack of trained and committed teachers will continue to weaken STEM education implementation at all learning levels, primary, secondary schools and tertiary institutions. Unfortunately, most schools facilities used for learning today were constructed before World War II and 40% were not built for STEM education rather for industrial arts (the National School Boards Association, 1996). Many schools are not equipped with the needed facility structure, tools and equipment and required instructional media. The government vis-à-vis school authorities should employ adequate STEM educators for teaching and learning STEM. When teaching materials are insufficient, teachers should learn to improvise (Nwanekezi et al., 2010). If changes are implemented as needed in our schools, this will enhance teachers' ability to facilitate learning activities to students, improve academic achievement and increase in state and national test scores (Ejiwale, 2012). The question here is, do these teachers refuse to improvise instructional materials or they do not know how to improvise?

10. Lack of hands-on training for students

Another feasible approach to implement STEM education successfully is to provide hands-on training for the young engineers needed by the industries of tomorrow. This is an opportunity for engineering students to take practical action for the future. Through this approach, students are going to understand what STEM area careers are by employing the machines used in the laboratories that are just similar to the ones they would use on the job. More important, student will use technology in the way one might if you are working in a STEM profession. In addition, a good internship and cooperative education will be beneficial. This reformation will make learning student-centered, sustenance of the role of STEM educators "from providing information to providing structure, support, and connections to the resources" (Glasgow, 1997, p. 123) will be the way to go.

For example, cooperative learning is successful not just because it is an alternative to lecture but because it allows some students the opportunity to process externally, to work with their peers, and to share responsibility for a task. Integrated curriculum is successful because it offers opportunities for connections that are made naturally in some students' minds and for the chance to study a topic in depth, which is appreciated by other students. Indeed, educational innovations that have "worked" can trace a relationship to some students' preferred learning patterns.

Conclusions

For STEM education to achieve its goals and objectives, addressing the barriers to STEM education should start by fixing the problems at the elementary, junior and senior high school levels. These are the grassroots and potential feeders to colleges and universities. Education has a bigger role to play for student's success in STEM education. There is need for in-service and outreach courses to help the efficiency and the performance of both in-service and veteran teachers in the classrooms. Professional development should be encouraged and continue to train teachers in effective classroom management so as to update their knowledge in the modern trend of teaching STEM education and to apply all they have learnt for effective teaching of students.

According to Mervis (2011), a successful science and math school is a successful school first, with skilled, knowledgeable teachers who address the needs of all students in a supportive, resource-rich environment. An inspired teaching inspires students. The success of facilitating student's activities depends on how well STEM educators have prepared for the challenges they will face when engaged in classroom/laboratory instruction. Students should be actively engaged in participatory activities in STEM programs. This reflects the shift in paradigm of the role of STEM educators, the form instruction should take and how it is delivered. The STEM educator should make sure that students are engaged in motivational activities that integrate the curriculum to promote "hands on" and other related experiences that would be needed to help solve problems as they relate to their environment. This could be more effective by allowing students to put into practice the actual roles played by people in the society like engineers, operators, supervisors to mention but few.

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