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Engaging Students In STEM Education

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ABSTRACT: With the "flattening" of the global economy in the 21st century, the teaching of Science, Technology, Engineering, and Mathematics (STEM) has taken on new importance as economic competition has become truly global. STEM education has evolved into a meta-discipline, an integrated effort that removes the traditional barriers between these subjects, and instead focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies. Engaging students in high quality STEM education requires programs to include rigorous curriculum, instruction, and assessment, integrate technology and engineering into the science and mathematics curriculum, and also promote scientific inquiry and the engineering design process. All students must be a part of the STEM vision, and all teachers must be provided with the proper professional development opportunities preparing them to guide all their students toward acquiring STEM literacy. By focusing on student engagement, educators from institutions of higher education and K-12 schools can work together to develop pedagogical models that provide rigorous, well-rounded education and outstanding STEM instruction. This paper defines the necessary attributes of STEM programs designed to engage all students, describes a number of model programs focused on student engagement, and discusses assessments in progress.

KEY WORDS: STEM; engaging students; meta-discipline; Project-Based Learning. (ICASE 2010 Tartu Declaration points - 3, 4, 5, 6, 8 and ICASE 2013 Kuching Declaration).

INTRODUCTION

The term "STEM education" refers to teaching and learning in the fields of science, technology, engineering, and mathematics; typically including

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ICASE member organizations:
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educational activities across all grade levels, from pre-school to post-doctorate, and in both formal and informal classroom settings (Gonzalez, & Kuenzi, 2012). While scientific inquiry involves the formulation of a question that can be answered through investigation, engineering design involves the formulation of a problem that can be solved through constructing and evaluating during the post design stage. STEM education brings these two concepts together through all four disciplines.

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

- Knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues.
- Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry and design;
- Awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
- Willingness to engage in STEM-related issues and with the ideas of science, technology, engineering and mathematics as a constructive, concerned, and reflective citizen." (p.101).

LITERATURE REVIEW

STEM Education has become an international topic of discussion over the past decade. This is driven by the changing global economy and workforce needs that indicate there will be a shortage of STEM prepared workers and educators around the world.

The International Council of Associations for Science Education (ICASE) released the Kuching Declaration on Science and Technology Education calling upon all involved in research, policy development, and the teaching of STEM disciplines to recognize the need to better prepare students for their future lives as global citizens. The declaration had input from participants representing 34 countries attending the ICASE World Conference of that same year. Thirty-four countries were represented at the conference. Part of the declaration included the following statement:

> *"Access to high quality education is a fundamental right for all. In times of global vulnerability, issues such as sustainability, health, peace, poverty alleviation, gender equity, and biodiversity conservation need to be at the forefront of thinking, planning and actions related to strengthening STEM education. While the relative balance and emphases of these disciplines varies around the world, it is the interrelatedness and combination of these that will propel progress." (ICASE, 2013).*

Improving teaching and learning in STEM education has become an economic factor in developing countries, emerging economies, and in long established economies such as Europe and the United States.

Modern economies have a rising demand for qualified researchers and technicians. One European initiative declaring STEM education as a major thematic domain is *inGenious*, organized by the European Coordinating Body in STEM Education through funding from the European Union as a joint initiative of European Schoolnet, the European network consisting of 30 Ministries of Education, in collaboration with the European Roundtable of Industrialists. The initiative released the publication Science, Technology, Engineering and Mathematics Education: Overcoming the challenges in Europe (Joyce & Dzoga, 2011), defining STEM education challenges in Europe and focusing on widening the STEM skills "gap" in European countries as compared to Asian countries. In particular, it noted that Asian STEM students account for about 20% of the student population compared to 2% in Europe.

The United States has also been examining the status of STEM education. Over the last decade, numerous reports from U.S. business and government organizations have warned that the United States' competitive edge in the global economy is eroding. These reports, along with a series of bills introduced in Congress and in state legislatures, call for an extensive effort to reform K–12 STEM education, and cultivate the next generation of skilled scientists, engineers, technicians, and science and mathematics educators (BHEF, 2007; Business Roundtable, 2005; NAS, 2007; NRC, 1996).

In 2010, President Obama's Council of Advisors on Science and Technology (PCAST) prepared an extensive report providing a two-pronged strategy for improving K-12 STEM education: Prepare and inspire the next generation of students. The five overarching recommendations contained in this report include (1) improve Federal coordination and leadership on STEM education; (2) support the state-led movement to ensure that the Nation adopts a common baseline for what students learn in STEM; (3) cultivate, recruit, and reward STEM teachers that prepare and inspire students; (4) create STEM-related experiences that excite and interest students of all backgrounds; and (5) support states and school districts in their efforts to transform schools into vibrant STEM learning environments (President's Council of Advisors on Science and Technology, 2010).

A 2011 follow-up report by the National Research Council (NRC) on successful K-12 STEM education cited 14 indicators related to tracking progress toward students' access to quality learning, educator's capacity, and policy and funding STEM initiatives. These indicators aim at creating and implementing a national-level monitoring and reporting system to assess progress toward key improvements; measuring student knowledge, interest and participation in STEM disciplines and STEM-related activities; tracking financial, human, capital, and material investments in K-12 STEM education at the federal, state and local levels; providing information about the capabilities of the STEM education workforce, including teachers and principals; and facilitating strategic planning for federal investments in STEM education and workforce development when used with labour force projections (National Research Council, 2012).

Although the United States is generally believed to perform poorly in STEM education, Gonzalez, & Kuenzi (2012) suggest that this negative perception may be due in part to the complex nature of the U.S. educational system and acknowledge that "by some measures, U.S. students appear to be doing quite well," citing "overall graduate enrolments in science and engineering (S&E) growing 35% over the last decade and enrolments for Hispanic/Latino, American Indian/Alaska Native, and African American students (all of whom are generally underrepresented in S&E) growing by 65%, 55%, and 50%, respectively" (p. 2). They further report that the condition of STEM education in the United States could be characterized as having "more or less held constant or improved over the course of the last four years" (p. 13). Projections for fall 2021 enrolments in grades 9-12 show the highest increase in student population will be represented by Hispanic/Latino students (Hussar & Bailey, 2013) indicating that additional bilingual expertise will need to be taken into consideration to meet the needs of U.S. classrooms in the future. In the United States, school-based factors that positively influence the success of traditionally underrepresented students in K-12 STEM education must include parental involvement and support, availability of bilingual education, culturally relevant pedagogy, early exposure to STEM fields, interest in STEM careers, self-efficacy in STEM subjects, and STEM-related educational opportunities and support programs (Museus, Palmer, Davis, & Maramba, 2011). In reality, these same factors positively influence the entire student population and ensure 21st Century Workforce Skills are attained: Global Awareness, Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy, Technology literacy, and Life and Career Skills including productivity and accountability, leadership and responsibility.

There are three broad goals for K-12 STEM education that are widely accepted in the U.S.: to increase advanced training and careers in STEM fields, to expand the STEM capable workforce, and to increase scientific literacy for all students (National Research Council, 2011). In other words, the overarching goal of STEM education in U.S. schools is to prepare all students for post-secondary study and the 21st century workforce. Nobel Laureate Physicist, Leon Lederman defines "STEM literacy" in a knowledge-based economy as the ability to adapt to and accept changes driven by new technology work with others (often across borders), to anticipate the multilevel impacts of their actions, communicate complex ideas to a variety of audiences, and perhaps most importantly, find "measured yet creative solutions to problems which are today unimaginable" (National Governors Association, 2007, p. 3). In order to ensure that STEM literacy is an expectation for all students and to improve the overall condition of STEM education in the United States, all students in all schools must be a part of the STEM vision and teachers must be provided with the proper professional development opportunities that will enable them to guide all their students toward acquiring STEM literacy (Crow, Kennedy, Odell, Ophus & Abbitt, 2013). If schools are to develop pedagogical models that provide a rigorous, well-rounded education with outstanding STEM instruction, and institutions of higher education are to facilitate the transformation of STEM and support professionals in these schools, an operational definition of STEM must go beyond literacy and simply teaching the four STEM disciplines, and focus on student engagement.

DISCUSSION: ENGAGING STUDENTS IN STEM IN THE U.S.

There are a number of U.S. STEM initiatives targeted at high school age (14-18 year old) students. The most notable of these are in the states of Massachusetts, North Carolina, Ohio, and Texas. The Texas initiative is particularly focused on transforming schools into academies that engage teachers and students in STEM with the goal of improving high schools and the college readiness of students (Texas High School Project, 2006). This is being accomplished through a number of initiatives including the Texas STEM (T-STEM) Initiative. T-STEM provides a context for looking at how STEM can be redefined to move beyond the boundaries of the separate disciplines that comprise STEM. T-STEM leaders developed a strategy to not only strengthen teaching the disciplines, but adopted and developed innovations to connect STEM at the secondary level to higher education and the workforce.

> *The Texas Science, Technology, Engineering and Mathematics Initiative (T-STEM) builds on state and local efforts to improve mathematics and science achievement among all Texas students and focuses on increasing the number of students who study and enter science, technology, engineering, and mathematics (STEM) careers. T-STEM offers a proactive and strategic approach to empower Texas educators with the tools needed to transform teaching and learning methods for the new century.*

Upon examination of the mission of the T-STEM initiative, it becomes apparent that the basic design of STEM extends beyond simply improving science and mathematics education. STEM education builds on reform efforts in mathematics and science education. The initiative focuses on increasing the number of students in the pipeline and ultimately the workforce. T-STEM recognizes that new educational tools and strategies are needed to *transform teaching and learning methods*.

> *To ensure that all Texas students thrive in the 21st Century economy, that Texas will continue to grow its economy, land more economic development opportunities, and remain at the forefront in the battle for 21st Century jobs, the Texas High School Project is carrying out a bold and forward-thinking education program – the Texas Science, Technology, Engineering, and Mathematics Initiative – T-STEM. As described by the National Academies of Science publication, Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future, innovation and design – the elements of STEM-related fields – should be the cornerstones of student learning.*

The T-STEM initiative mission highlights the elements of STEM-related fields as being the cornerstones of student learning. The mission expands the scope of traditional K-12 STEM education which conventionally focuses on the fundamental basics of science and mathematics. STEM education, within the T-STEM context, should also integrate engineering and technology within the overall student experience.

IMPACT OF T-STEM ACADEMIES

In 2013, there were 65 T-STEM Academies serving over 35,000 students in Texas. T-STEM Academies seek STEM Designation from the Texas Education Agency (TEA). School districts or open-enrollment charters may apply for a campus to be awarded T-STEM designation if certain criteria are met. Campuses awarded T-STEM designation are provided technical assistance and professional development to ensure implementation of the T-STEM Blueprint with fidelity. Sample designation criteria are listed below:

- Target and enroll students who are at-risk of dropping out of school
- Be a school of choice with no requirements for enrollment such as test scores, essay questions, etc.
- Serve grades 6-12 or grades 9-12 with an active relationship with the feeder middle school(s)
- Implement the T-STEM Blueprint (www.tstemblueprint.org) and demonstrate progress on the Blueprint continuum.

The T-STEM Blueprint focuses on seven benchmarks. These benchmarks are assessed using the T-STEM Design Blueprint Rubric (www.tstemblueprint.org/rubric/). The rubric focuses on indicators for each of the benchmarks. The benchmarks include:

1. Mission Driven Leadership
2. T-STEM Culture
3. Student Outreach, Recruitment, and Retention
4. Teacher Selection, Development, and Retention
5. Curriculum, Instruction and Assessment
6. Strategic Alliances
7. Academy Advancement and Sustainability

PERFORMANCE OF T-STEM ACADEMIES

To date T-STEM academy students outperform students from comparison schools with similar demographics.

- 9th grade T-STEM students had higher likelihoods of passing Algebra I than peers in comparison schools.
- 10th grade T-STEM students scored higher than comparison students on the Texas Assessment of Knowledge and Skills (TAKS) Math.
- 10th grade T-STEM students had higher likelihoods of meeting or exceeding TAKS standards in all subjects.
- 86.3% of students at T-STEM Academies passed the Math TAKS compared to the state average of 83%.
- 87.3% of students passed the science TAKS as compared to the state average of 84%.
- T-STEM students had a higher attendance rate than those in comparison schools.
- Schools implementing the T-STEM Academy Blueprint saw significant drops in referrals for inappropriate behaviors.

It is anticipated that there will be over 100 T-STEM Academies by 2015 in Texas. There is significant evidence that the T-STEM model has a positive impact on student achievement and college readiness. The model has also proven replicable across a diverse set of schools.

DISCUSSION

As indicated earlier, STEM is typically used as an acronym for four separate discipline areas of Science, Technology, Engineering and Mathematics. The current high school curriculum in Texas aligns well with this approach. Students preparing for college complete four years of mathematics and science; however, these students have not typically had access to courses or experiences in technology and engineering. The typical student enrolls in biology, physics, chemistry, and an advanced science. In mathematics, the pathway is commonly Algebra I, geometry, Algebra II, and pre-calculus. Most students in the college pathway do not enroll in any technology or engineering courses. The state of Texas has revised its standards, the Texas Essential Knowledge and Skills, to include engineering and to make technology courses available to non-tech prep students. However, simply making courses in engineering available will not guarantee that students will enroll in them considering many students enroll in Advanced Placement and other elective science classes.

This trend indicates that despite the best efforts in curriculum reform, most students will not receive the breadth of STEM education as they will not have access to all of the separate STEM disciplines. If students are to be engaged in all of the STEM disciplines, the definition of STEM education must go beyond improving the individual STEM disciplines and look at STEM more holistically. In 2007, Microsoft Founder Bill Gates provided testimony to the U.S. Congress concerning STEM education.

> *Bill Gates (in Testimony…), emphasized that there are two approaches to improving STEM education: one takes curriculum at normal schools and makes it better, the other involves STEM-specific schools. He went on to note that many schools are using curricula that focus on projects which purposefully cut across subject boundaries—boundaries of biology being different than chemistry, chemistry being different than math, and so on.*

The statement above reinforces the two possible strategies, improving the current separate STEM curricula, or developing curricula that cut across these boundaries. STEM becomes an interdisciplinary approach to teaching. The Bill and Melinda Gates Foundation is funding schools in the U.S. to implement this approach to improve STEM education. The National High School Alliance provides the following discussion of STEM:

> *"Science, technology, engineering and mathematics (STEM) education is a relatively new mode of thinking about how best to educate high school students for the workforce and for post-secondary education.*
>
> *STEM education is not simply a new name for the traditional approach to teaching science and mathematics. Nor is it just the grafting of "technology" and "engineering" layers onto standard science and math curricula. Instead, STEM is an approach to teaching that is larger than its constituent parts; it is, as Janice Morrison of the Teaching Institute for Essential Science stated, a "meta-discipline."*

> *STEM education removes the traditional barriers erected between the four disciplines, by integrating the four subjects into one cohesive means of teaching and learning. The engineering component puts emphasis on the process and design of solutions instead of the solutions themselves. This approach allows students to explore math and science in a more personalized context, while helping them to develop the critical thinking skills that can be applied to all facets of their work and academic lives. Engineering is the method that students utilize for discovery, exploration, and problem-solving.*
>
> *The technology component allows for a deeper understanding of the three other parts of STEM education. It allows students to apply what they have learned, utilizing computers with specialized and professional applications like Computer Assisted Design (CAD) and computer animation. These and other applications of technology allow students to explore STEM subjects in greater detail and in a practical manner.*

It is this definition that may offer insight into how to make STEM more interesting to students and fully engage them in all four subject areas. Innovative curricular programs, which connect the four discipline rather than simply strengthening existing mathematics and science courses may hold the key to improving student engagement.

CONCLUSION AND RECOMMENDATIONS: STEM EDUCATION INTEGRATION

Based on the discussion above, the following recommendations have been developed. While these recommendations are intended for high school STEM educators, it is recognized that they have direct implications for all P-20 STEM educators. Curricula that engages students in STEM promotes instructional strategies that challenge students to innovate and invent. This indicates students have to apply the science and mathematics knowledge they learn to an engineering problem and utilize technology in finding a solution. In this approach, students are required to demonstrate their understanding of STEM disciplines in a work-based, contextual environment. To do this, teachers must be able to offers standards-based STEM programs that use innovative instructional tools. That is to say that if teachers are prepared and have the tools, STEM can promote applied and collaborative learning. Technology has to be integrated into the culture, curriculum, teaching strategies and daily operations of classrooms to enhance learning and provide relevance. It is at this point that STEM becomes a meta-discipline and needs to be delivered to students in an interdisciplinary manner, within the constraints of the national/state course guidelines.

Elements of Engaging STEM Education Programs

High quality STEM education programs and curricula should reflect the following features:

- Include rigorous mathematics and science curriculum and instruction;
- At a minimum, (if separate STEM courses are not available in all areas) integrate technology and engineering into the science and mathematics curriculum;
- Promote engineering design and problem solving—(scientific/engineering) the process of identifying a problem, solution innovation, prototype, evaluation, redesign —as a way to develop a practical understanding the designed world;
- Promote inquiry—the process of asking questions and conducting investigations—as a way to develop a deep understanding of nature and the designed world (NSTA 2004);
- Be developed with grade-appropriate materials and encompass hands-on, minds-on, and collaborative approaches to learning;
- Address student outcomes and reflect the most current information and understandings in STEM fields;
- Provide opportunities to connect STEM educators and their students with the broader STEM community and workforce;
- Provide students with interdisciplinary, multicultural, and multi-perspective viewpoints to demonstrate how STEM transcends national boundaries providing students a global perspective;
- Use appropriate technologies such as modeling, simulation, and distance learning to enhance STEM education learning experiences and investigations;
- Be presented through both formal and informal learning experiences;
- Present a balance of STEM by offering a relevant context for learning and integrating STEM core content knowledge through strategies such as project-based learning.

K–16 teachers of STEM, school and district leaders, community college and university STEM leaders, and other key stakeholders should embrace the following key points:

- Teachers of STEM should recognize the compelling and inherent opportunities of STEM to strengthen and support the teaching of STEM education, and, where possible, integrate STEM applications into the curriculum.

- Teachers of STEM should seek out and participate in quality professional development opportunities to enhance their knowledge of STEM and its application in meeting curricular requirements, and to gain exposure to practicing STEM professionals.
- Teachers of STEM should locate and use quality resources from STEM organizations to enhance and strengthen their curricula.
- School administrators and principals should support teachers in their efforts to integrate STEM within science and mathematics curricula.
- Collaborations among stakeholders in education, government, business, the community, and the media should be encouraged to coordinate the development and availability of STEM educational resources.

STEM as an interdisciplinary discipline requires that pedagogical approaches must be altered from traditional approaches to support student learning.

- STEM Educators must implement instructional strategies that integrate the teaching of STEM in a way that challenges students to innovate and invent.
- STEM Educators must use problem-based and project-based learning with a set of specific learning outcomes to support student learning.
- STEM Educators must create meaningful learning opportunities provided context learning is delivered using applied and collaborative learning.
- STEM Educators must require students to demonstrate their understanding of these disciplines in an environment that models real world contexts for learning and work.
- STEM Educators must provide students with interdisciplinary, multicultural, and multi-perspective viewpoints to demonstrate how STEM transcends national boundaries providing students a global perspective that links students with a broader STEM community and workforce.

High quality STEM education programs provide teachers with opportunities to collaborate with one another in unified efforts aimed at integrating the four subjects into one cohesive means of teaching and learning. It is when this objective is achieved that students gain access to meaningful curricular opportunities promoting critical thinking skills that can be applied to their academic as well as everyday lives.

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