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How STEM Education Improves Student Learning

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Abstract

The intent of this article is to examine current taxonomies used to design and deliver Science, Technology, Engineering, and Mathematics (i.e., STEM) curriculum in an effort to attract a greater variety of students to the STEM field of study in the K-12 public school environment. I analyzed specific aspects of STEM-based programs to compare STEM education components to traditional college-preparatory methods of instruction, including looking for environmental practices that may attract female and first-generation college attendees toward developing a positive attitude toward attaining a STEM education. I also made connections between current instructional trends and their impact on student mastery.

Keywords: STEM, integration, student-centered, problem solving

How STEM Education Improves Student Learning

Science, Technology, Engineering, and Mathematics (i.e., STEM) education has emerged as one of the most sought after curriculum designs for integrating science, technology, engineering, and mathematics into K-12 education. It first became popular as a means of serving the needs of mathematically gifted students, providing opportunities to both accelerate learning and increase the rigor and depth of learning. This combination afforded opportunities for motivated students to advance into special classes, including taking college classes in high school and receiving college credit for advanced classes taught during high school (Wai, Lubinski, Benbow, & Steiger, 2010). Empirical studies have concluded that course acceleration in itself is not a strong enough factor to improve individual learning; however, learning activities where students practice using integrated skills to solve problems allow for deeper and more meaningful student learning (Wai et al., 2010). Originally, STEM education was directed at highly talented students (especially in Mathematics) and highly motivated students who were interested in exploring and learning a greater depth of material at a faster pace to practice strong reasoning skills and to develop and strengthen learning. STEM education attracted a concentrated population until practices and methods were integrated into mainstream K-12 education and seen as opportunities to provide equity for motivated but disadvantaged students from a variety of backgrounds. “In 1983, A Nation at Risk (National Commission on Excellence in Education [NCEE], 1983) established the resurgence for the science, technology, engineering, and mathematics (STEM) movement in education” (Mahoney, 2010, p. 24).

The call for STEM integration to better secure the future of American education, and America itself, led to the development of national standards in education, developed by organizations such as the National Council of Teachers of Mathematics, the American Association for the Advancement of Science, the National Research Council, and the International Technology Education Association (Mahoney, 2010). Design and implementation of the curriculum infused with the four essential STEM subjects has produced a variety of teaching models and practices, making it difficult to evaluate program effectiveness. Some common educational practices include educational discovery as a form of problem solving, cooperative learning, and subject integration; thus encouraging students to work together to design solutions to problems in a foundational and authentic environment using real-world data and problems. According to Mahoney (2010), there has been little research done to study the improvement in learning using the aforementioned instructional practices.

Most high school STEM programs have adopted national standards of curriculum alignment; the common strands have aligned themselves to increase student engagement, motivation, and learning. Reportedly, in 2005, interest in engineering careers had dropped significantly, and attitudes toward STEM studies were waning. Although there was a paucity of empirical evidence supporting STEM education's influence on improved learning, pedagogical learning models had been explored and documented. Many of the models adopted and used in STEM education environments had made significant gains on improved student learning, and not solely with the academically gifted population. Student attitudes toward STEM education proved to be a major factor when addressing the needs of the student's affective domain in order to increase individual motivation (Mahoney, 2010).

As recently as 2006, design courses such as engineering have impacted student achievement, as measured by standardized math tests (Dyer, Reed, & Berry, 2006). Educators are eager to reduce performance gaps among particular ethnicities and socio-economically disadvantaged students by refining student skills. Moreover, learning activities are designed to focus on student engagement, knowledge acquisition, literacy analysis, synthesis, and critical thinking skills that will impact the depth of student learning.

Many of the engineering principles and reasoning skills integrated into the K-12 STEM curriculum are promoted using existing learning models that are not newly developed but are newly modified. Existing programs, like Project Lead the Way and Energy Projects in Community Service-Learning (EPICS) High, include some problem-solving skills but lack "systematic and rigorous research" that may show how learning is impacted (Kelley & Pieper, 2009). These STEM programs include powerful pedagogical practices centered on the student's active learning, including cross-curricular integration, project-based learning, authentic and alternative assessments, writing literacy via research and reflection, creating partnerships with the business community, and solving or attempting to solve authentic, real-world problems. Instead of targeting only the gifted population, the EPICS High program includes 650 students in 32 high schools across the nation, including "50% female students, 48% minority students, and over 50% in free and reduced lunch programs" (Kelley & Pieper, 2009). A key part of this curricular model includes using a systematic approach to solving problems. The theory behind the systematic approach is that students will be better prepared to use learned engineering processes when attempting to solve problems in other situations or courses (Kelley & Pieper, 2009). Students are learning and building skills that can be applied to a variety of situations, including making room for student innovation and original design.

Integrating engineering instruction and problem solving into high school mathematics and science courses connects curriculum to the real world, thus providing authentic purposes for learning and solving problems. Instructional strategies have been designed and implemented to strengthen teachers' efforts to facilitate engineering concepts and processes when students are learning science and math within an integrated learning environment (Rockland et al., 2010). Rockland and colleagues explained that "science can be viewed as proposing explanations for questions about the natural world, whereas engineering proposes solutions for problems of human adaptation to the real world" (Rockland et al., 2010, p. 54). Discovery, problem solving, and inquiry-based learning all play strong roles in STEM integration. Often students use cooperative learning to work in teams to research and complete tasks, to test theories, and to plan and implement processes and solutions. Learning is maximized because students share prior knowledge, play on one another's best skills, and utilize one another for discovering new and important information. Citing Harwood and Rudnistsky (2005), Rockland and colleagues indicated that such learning practices can make learning more relevant because they "can stimulate students as well as enable them to recognize links between their lessons and tasks performed by engineers in the real world" (p. 54).

Teaching science and engineering in the integrated format also allows for other content areas to find natural places to integrate. Math teachers should plan and communicate with other teachers and with students to correctly time instruction for specific mathematics skills prior to needing specific skills for use in engineering or science instruction. Integrating social studies curriculum provides students opportunities to examine economic, political, and social issues that can directly or indirectly impact design decisions. Reading, writing, and speaking are important aspects of communication and should also play an integral role in curriculum alignment. Aligning the curriculum in this way helps students make purposeful and useful connections for math skills while they are building and practicing those skills in authentic learning environments, providing the learner with a clear lens to view the entire picture.

Inquiry-based learning is another learning model where the students become scientists in order to discover information. The National Science Education Standards highly recommend this instructional approach. Not only are critical thinking and reasoning skills explicitly taught using the scientific inquiry process, but students also personify what it is like to research, test, discover, and think like a scientist. They learn the development of knowledge and cultivate an understanding for the importance of reasoning and thinking like a scientist in order to appreciate how evidence is used to understand and support commonly accepted theories and beliefs (Rockland et al., 2010). Engineering becomes the active engagement students need to internalize learning by collaborating and creating solutions for real-world problems. Technology, science, and math are the tools students must use to engineer their solutions. Literacy and writing are important for students to understand the history of previous attempts to solve problems. Speaking and communicating are essential for collaboration and persuasion. While STEM stands for the integration of science, technology, engineering, and mathematics, it really requires skills and knowledge from all content areas, including the arts. Design plays a significant role in engineering; one must be innovative, creative, and original when constructing authentic designs. Clearly knowing the science and math behind a solution is important, but 21st Century Skills also call for innovation and creative design.

Multimedia-based case study is another learning model that challenges students to analyze case studies developed using multimedia formats that are creative and technical in nature (Jarz, Kainz, & Walpoth, 1997). Multimedia elements are integrated as “didactic element(s)” where the emphasis is placed on learning and then communicating information. The didactic focus for information delivery is on both the entertainment aspect and the learning aspect; this learning model expects the learner to enjoy and interact with learning content. Students solve real problems using solutions and information that others have learned while attempting to solve similar problems. Learning from history, learning from others’ mistakes, and learning from others’ wisdom are all essential elements of this model. The learner analyzes the information that is collected, structured, and disseminated using video and other multimedia formats. The learner must actively apply deep learning from the multimedia and the case studies to solve or test for possible solutions to the problem rather than merely acting as a consumer of video content. The case studies anchor the instruction while the multimedia provides the context for understanding and for assessing the information, while also providing suggestions for solutions and opportunities for learners to critically analyze suggestions established in the case studies (Wang, Moore, Wedman, & Shyu, 2003).

Multimedia comes in many forms and can be used to develop and increase fluency. It provides learners with purpose, context, potential motivation, and can also tap into the real- world connectivity realm for many learners. Multimedia becomes an alternate pathway to knowledge that can facilitate conceptual vocabulary development when strategically used to introduce a new concept or provide background or prior knowledge for learners with deficiencies (Bransford et al., 1992). This creates equity for students whose skills make learning difficult because they are unable to make connections to prior experiences or for students who are lacking prior knowledge. Although a student may be unable to read a rigorous text, he or she will make meaning and perhaps dig deeper in content that interests him provided through the words, ideas, and concepts presented using multimedia.

Professional Development and Pedagogical Shifts

It is my contention that traditional teaching methods will not support STEM instruction. The aforementioned instructional models require students to be actively engaged in cooperative learning environments where their instructors help facilitate creativity and inquiry learning. Rockland and colleagues suggest STEM instructors undergo professional development “aligned” and “designed to train teachers to use” integrated curriculum (Rockland et al., 2010). Several STEM curriculums have been aligned and designed to teach the integrated standards. Medibotics curriculum uses LEGO™ MINDSTORMS in schools that utilize ROBOLAB software, using an “icon-based, diagram-building environment to write programs,” based on LabVIEW™, a popular software used in biomedical engineering (Rockland et al., 2010, p. 56). Students learn to program and build robots, exposing them to many science fields, including biology, medicine, engineering, and physics as well as information technology (Rockland et al., 2010). There are other brands of robotics that can be used to integrate engineering and technology instruction into the teaching of science objectives. Rockland and colleagues suggest that by integrating robotics, students are acquiring knowledge while refining their critical thinking skills. Students are afforded opportunities to learn science concepts in the hands-on environment, practicing and applying skills and knowledge. Students see and experience applied concepts and are better able to apply learned concepts to solve future problems and to transfer application to new situations.

Teachers will need to develop an understanding for working with engineering curriculum in order to better integrate and modify existing curriculum so that K-12 courses promote engineering design principles (Rockland et al., 2010). This can be seen when integrating Social Studies with engineering as students examine structures and technology manufactured by different cultures for varying needs in specific time periods (Rockland et al., 2010).

Merely writing engineering standards into curriculum will not necessarily improve or increase how it is being taught. Since engineering primarily focuses on problem solving and student-learning outcomes, the standards need to be integrated across all content areas at all levels of K12 education (Rockland et al., 2010). Staff development and training are necessary for teachers to effectively integrate project-based learning with engineering concepts into the previously established learning objectives. Rockland and colleagues suggest using an instructional framework “for pre-service teachers to blend engineering concepts” whereby the learner can more easily read, comprehend, and apply learning to all aspects of education (Rockland et al., 2010, p. 59). The “Preparation, Assistance, and Reflection (PAR)” framework suggests teachers pre-assess where students are in their background knowledge and skills before they begin exchanging ideas in a cooperative learning environment (Rockland et al., 2010, p. 59).

The engineering portion of STEM education allows for student exploration of the what and how of learning across all stages of the curriculum. Because there are no formal engineering standards measured, integration can and must lead to finding natural fits in order to maximize student learning through making connections.

A significant role when integrating engineering into K-12 curriculum understands a student's own interest. Providing choices and hands-on activities where students complete problem-based tasks such as building “transistor radios, burglar alarms, electronic timers, telephones, cameras, computers, robots” and more helps students answer the how from the PAR learning model (Rockland et al., 2010, p. 59). Some teachers may find it difficult to adopt or adapt to including design projects in a typical K-12 environment, which is why staff training and professional development are so important. Teachers should also be given the opportunity to share what they already know with their students. Rockland and colleagues provide an example of a teacher who brought in her guitar to demonstrate sound energy with her students; she also used household items from the recycling bin to allow students to experiment and build things that interest them during core classroom time (Rockland et al., 2010).

The advantage to integrating STEM curriculum into all content areas at all grade levels is that it provides students with informal practice creatively solving problems long before they need to decide on a course of study for college. The opportunity to practice and understand engineering skills opens up a world of possibilities whereby students already have some experience and prior knowledge as to what their careers may be like. Using engineering design principles to complete hands-on, problem-based projects also deepens the student's understanding of processes and emphasizes many of what we now call 21st Century Skills (e.g., collaboration, critical thinking, and interpersonal communication). Furthermore, STEM integration can become a seemingly typical part of the learner's educational experience on a daily basis, removing emphasis on gender lines and closing achievement gaps as students hone and master critical thinking skills.

The PAR model focuses on clearly defined learning outcomes and on each student mastering new knowledge at his or her own pace before moving to new material. Rockland and colleagues suggest students

> (P) encounter new knowledge (discovered or presented), (A) have knowledge modeled with an opportunity to practice in order to verify success or, if not success, correct learned behavior by being re-taught and allowed to practice again the new knowledge, until learning has been achieved to the level of expectation for the individual. . . .[and that] additional practice of new knowledge in similar and/or diverse settings during the (R) reflection stage stabilized the learner's intake of the new concept while the assessment, directly linked to that which occurred in the PAR phase, ensures the student and the teacher that learning has taken place (Rockland et al., 2010, pp. 60-61).

The emergence of STEM curriculum in the public K-12 educational system provides opportunities for all level learners to master skills and content important for 21st Century learning. Using a variety of activity-based learning models, students are provided opportunities to accelerate to rigorous depths of learning. Learning is facilitated so that students are encouraged to delve deeper into topics that interest them individually. Developing students' reasoning skills, critical thinking skills, creativity, and innovation through integrated and connected STEM curriculum and pedagogical practices provides equity among learners from diverse backgrounds. STEM curriculum has the potential to provide true mastery for all learners.

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