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Integrated STEM Assessment Model

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ABSTRACT
Previous research identified a strong correlation between mathematics and science performance albeit for small samples of students. Even though there was a high correlation between mathematics and science performance, researchers examining students' STEM achievement investigated mathematics and science achievement separately. The present study brings science and mathematics objectives together to constitute a higher order STEM assessment model. Data (science and mathematics scores) were gathered from 231,966 students (52% female) who were in 11th grade and took the state mandated test in 2013. A second-order confirmatory factor analysis was used to create a STEM assessment model. The fit indices showed indicated it was an adequate model fit for the data. However, the lack of assessments of technology and engineering objectives taught in K-12 make estimating the effectiveness of STEM teaching and learning tenable at best.
Keywords: STEM assessment model, STEM assessment, STEM education

STEM EDUCATION

In the United States, a general call for reform has been raised for the teaching and learning of science, technology, engineering, and mathematics (STEM). The increased concern for student achievement and interest in STEM fields was a result of international comparisons. It was determined that the United States was losing ground in the competitive labor market, falling behind in the creation of new and innovative ideas, and students in the United States were underperforming their international peers in mathematics and science (Augustine, 2005). Companies were employing people and businesses in other countries to perform tasks that required advanced skills, which increased pressure on the domestic U.S. worker. Of the top ten companies earning patents from the United States patent office in 2003, only three were from the United States. The Programme for International Student Assessment (PISA) results showed that students in the United States were outperformed by many nations in mathematics and science, ranking 27th in mathematics and 20th in science (Organization for Economic Co-Operation and Development, 2012). These results spurred governmental review and

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State of the literature

- The decision to lump science, technology, engineering, and mathematics together was the result of a clear need to increase student achievement in these areas.
- The natural cohesion of the STEM fields may be due to deeper, cognitive reasons. Research has shown that one way that STEM fields could be related is through required spatial thinking. Although spatial thinking is often considered to be in the realm of mathematics, it is necessary such concepts as the structure of atoms and compounds in chemistry and for many applications in physics.
- The tests evaluated students on various subjects, yet the combined areas of STEM together were the national concern. This led the researchers to investigate the relationship between student performance on standardized tests in mathematics and science. There was a strong correlation between students' mathematics and science performances. This relationship might provide the beginnings of a theoretical framework for assessing STEM learning. Although a high correlation between mathematics and science scores was reported, researchers who tried to examine STEM achievement of students investigated students' mathematics and science achievement separately.

Contribution of this paper to the literature

- The result suggests that science and mathematics objectives together constitute a hierarchical model, and this model yields good model fitness.
- If STEM achievement is of interest to researchers, it might be more appropriate to construct a model that covers mathematics and science disciplines jointly.
- Future research about STEM assessment models should consider STEM disciplines jointly, and test the model with science and mathematics objectives as we did in the present study, as well as including estimates of technology and engineering achievement.

reassessment of how best to allocate funds and bring about improvement in these critical STEM areas (National Science and Technology Council, 2011; 2013).

The decision to lump science, technology, engineering, and mathematics together was the result of a clear need to increase student achievement in these areas. It was also a reality that the STEM fields share many commonalities that can enhance learning. Because STEM fields were synergistic hot beds for new inventions and discoveries, low performance in these areas threatened the economic stability and innovative leadership status that the United States enjoyed for many years (National Science and Technology Council, 2011).

The STEM subject areas could also be integrated for reasons other than international comparison concerns. Many science topics require proficiency in mathematics in order to understand concepts and processes, while mathematics devoid of its scientific context could be seen as a subject worthy of study only for its own sake. However, it is from the nexus of these two core subjects that technological and engineering innovations often arise. So, while the label "STEM" may have originated due to international concerns, the grouping of these subjects was more natural than simply sharing urgency for improvement.

The natural cohesion of the STEM fields may be due to deeper, cognitive reasons. For example, research has shown that one way that STEM fields could be related is through required spatial thinking. Although spatial thinking is often considered to be in the realm of mathematics, it is necessary such concepts as the structure of atoms and compounds in chemistry and for many applications in physics. Those students who could think spatially were eventually more likely to pursue STEM careers regardless of overall mathematics proficiency (Wai, Lubinski, & Benbrow, 2009). Identifying spatial thinking as an indicator of future STEM attainment opened the door for discussions concerning how best to increase student spatial thinking ability (Newcombe, 2010). Developing a single skill, such as spatial thinking, to increase performance in STEM fields may indicate the deeper, cognitive connection between the subjects. Thus, research on the human brain and how it best learns, retains, and uses information could be applied to the field of STEM education. Research about the human brain has not indicated that one part of the brain was discretely responsible for mathematics, or science, or English; rather, research showed that the brain works best as a cohesive unit, with different parts processing information or performing different tasks such as motor control, auditory processing, visual processing, learning, memory, or producing emotions (Freudenrich & Boyd, 2015). One part of the brain may process the verbal explanation of an object while another part of the brain may process the visual shape of the same object, but to best understand what the object was, both pieces must be understood together. This unification occurs within the brain to precipitate new learning. The application of research about the human brain applied to education, resulted in the development of brain-based teaching strategies (Caine & Caine, 1997; Jensen, 2000a, 2008). The use of brain-based research for understanding learning and its application in classrooms was not without critics (Davis, 2004; Jensen, 2000b). Regardless, the fact that STEM areas were unified could have had as much to do with the natural relationship these fields share as the urgent need to improve internationally.

The unification of the subjects, while productive academically and intellectually, has proven to have major issues. Given the current educational climate for teacher and school accountability, students spend more time in technology and engineering classes; yet that learning has not contributed to meeting state goals for teacher or school accountability. There were too few instruments for measuring student learning in technology and engineering. For example, the National Assessment of Educational Progress (NAEP) measured whether students apply technology and engineering skills to their real-life situations. Those instruments that have been used are not common even within a district, much less across the nation. It has been difficult to assess whether or not the curricula, instruction, or adopted materials translated into transformative knowledge that would lead students to post-secondary success.

EDUCATION STANDARDS AND TESTING

National science and mathematics standards were created, and states were given the option to either adopt them or to develop their own of equal or greater value. These new standards were the Common Core State Standards for Mathematics (CCSSM) (Common Core Standards Initiative, 2010) and the Next Generation of Science Standards (NGSS) (Achieve, 2013). The Common Core standards were developed based on the current understanding of best preparation practices for students and by investigating the standards of top-performing countries (CCSS Initiative, 2015). The science standards were developed based on an international benchmarking study, thus creating standards that were comparable to those of the best performing nations in science (Achieve, 2010). One result of having uniform standards was the ability to then develop standardized tests to assess student performance and progress. Traditionally, state tests have taken many forms, making comparisons across states nearly impossible. Texas developed mathematics and science standards, and requisite assessments were created in lieu of adopting the CCSS. The Texas Assessment of Knowledge and Skills (TAKS) test was administered across grade levels and subjects (Texas Education Agency, 2015). The four subject areas assessed were English language arts, mathematics, science, and social studies. The tested content was based on the Texas Essential Knowledge and Skills, the curriculum standards unique to the state of Texas. These standards separated mathematics and science into two different categories; however, concepts and applications of science and mathematics often caused these disciplines to intermingle.

Correlation between Mathematics and Science Scores

The urgent need for a more educated and capable STEM workforce and the fact that the United States has performed inadequately on the international stage made education reform in the STEM areas a national concern. Initiatives were taken to address the issues by establishing STEM schools and creating national standards. Large scale testing of students on the state and national levels provided opportunities for interested parties to investigate the effectiveness of reform and potentially highlight areas of further interest. However, all testing was done on individual subject matter, with no testing of integrated mathematics and science and no studies of the effects of combined mathematics and science scores.

The tests evaluated students on various subjects, yet the combined areas of STEM together were the national concern. This led the researchers to investigate the relationship between student performance on standardized tests in mathematics and science. Cetin, Corlu, Capraro, and Capraro (2015) found a strong correlation between mathematics and science performance by using a statewide dataset. This relationship might provide the beginnings of a theoretical framework for assessing STEM learning. Although a high correlation between mathematics and science scores was reported, researchers who tried to examine STEM achievement of students investigated students' mathematics and science achievement separately. The present study's aim is to develop a hypothesized model (see **Figure 1**) by which STEM achievement of schools or students can be measured by considering the STEM disciplines as one construct rather than measuring each STEM discipline separately when STEM achievement of students or schools is of interest of researchers. However, assessing the model fit for the hypothesized STEM assessment model is currently not possible because students' technology and engineering scores are not yet measured in K-12 education (NRC,

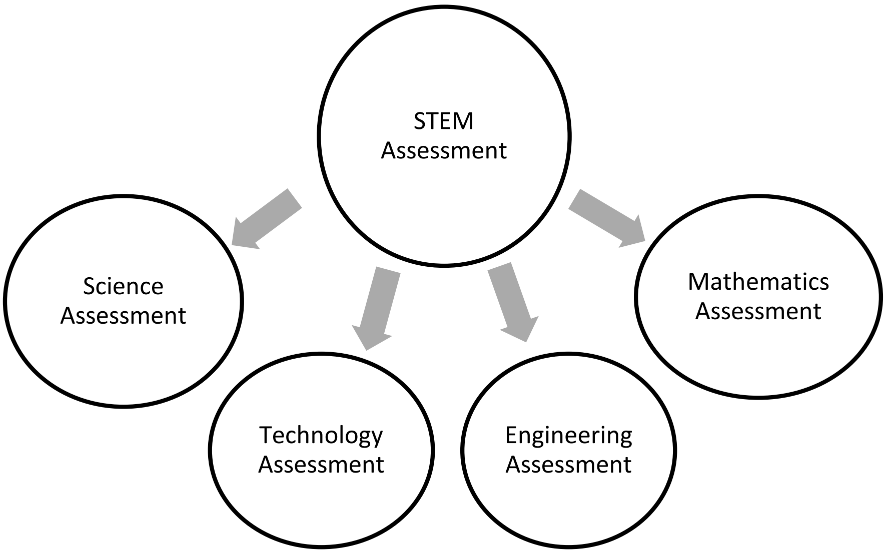

Figure 1. STEM assessment model

2011). NRC (2011) reported that educational studies "in technology and engineering education is less mature because those subjects are not as commonly taught in K-12 education" (p. 8). This is expected to change because several types of STEM schools have emerged, and these schools implemented technology and engineering oriented curriculum and classroom practices. Therefore, one construct to assess STEM achievement of schools and individual students is essential. This study advocates adding an integrated STEM assessment model to see if students can use the various STEM skills and knowledge in an interdisciplinary way.

METHOD

In the present study, confirmatory factor analysis (CFA) was applied to test the STEM assessment model based on the reported correlation between science and mathematics scores of students. Structural equation modeling (SEM) by using Mplus 7.4 was used to determine whether students' understanding of science and mathematics together constitute a higher order model. Because students' performance in technology and engineering were not measured systematically by the state or across schools or districts, it was not possible to include technology or engineering. Applying higher-order confirmatory factor analyses was appropriate because it has the capacity to test hierarchical dynamics of the model (Thompson, 2006).

Data Sources

Data were obtained from the Texas Education Agency (TEA), the administrators of the Texas Assessment of Knowledge and Skills (TAKS) test. For the present study, data were gathered from 231,966 students (52% female) who were in 11th grade and took the TAKS test

Table 1. TAKS 11th Grade Mathematics and Science Objectives

TAKS	Obj	Explanation
TAKS Mathematics	1	Understanding functional relationships
	2	Recognizing properties and attributes of functions
	3	Understanding linear functions
	4	Identifying linear equations and inequalities
	5	Formulating quadratic and other nonlinear functions
	6	Reasoning geometric relationships and spatial reasoning
	7	Representing 2D and 3D representations
	8	Understanding measurement concepts
	9	Using percent, proportions, probability, and statistics
	10	Demonstrating mathematical processes and tools
TAKS Science	1	Understanding nature of science
	2	Demonstrating organization of living systems
	3	Demonstrating interdependence of organisms
	4	Understanding structures and properties of matter
	5	Understanding and connecting motion, forces, and energy

in 2013. The scope of the content assessed was student science and mathematics objectives scores (see in **Table 1**). The total number of objectives was 15, 10 from mathematics and 5 from science.

Model Fit Evaluation

The fit indicies for the model were as follows: a) chi-square = 39802 (p < .01) with 89 degrees of freedom (*df*), b) comparative fit index (CFI) = .983, c) root mean square error of approximation (RMSEA) = .044, and d) standardized root mean square residual (SRMR) = .018. Reporting chi-square as one of the model fit indices was important, but it was more important to remember that chi-square is sensitive to sample size. Due to the large sample size of the present study, chi-square yielded a large quantity, and it was statistically significant (p < .01). The other fit indices indicated a good fit for the data. In the present study, a model with science and mathematics factors allowed the factors to freely co-vary in order to see whether there was any difference in the fit indices. The results showed that the model in which science and mathematics factors were allowed to be correlated yielded better model fit indices. To obtain a good model fit, the RMSEA should be lower than .06, the CFI should be higher than .95 (Hu & Bentler, 1999), and the SRMR index should be lower than .05. As can be seen in **Figure 2**, the factor loading values for each variable were larger than .4 and each path was statistically significant (p < .01).

DISCUSSION

STEM achievement of students in the U.S. has recently become one of the most appealing topics in education (Bicer, Navruz, Capraro, & Capraro, 2014; Bicer, Navruz,

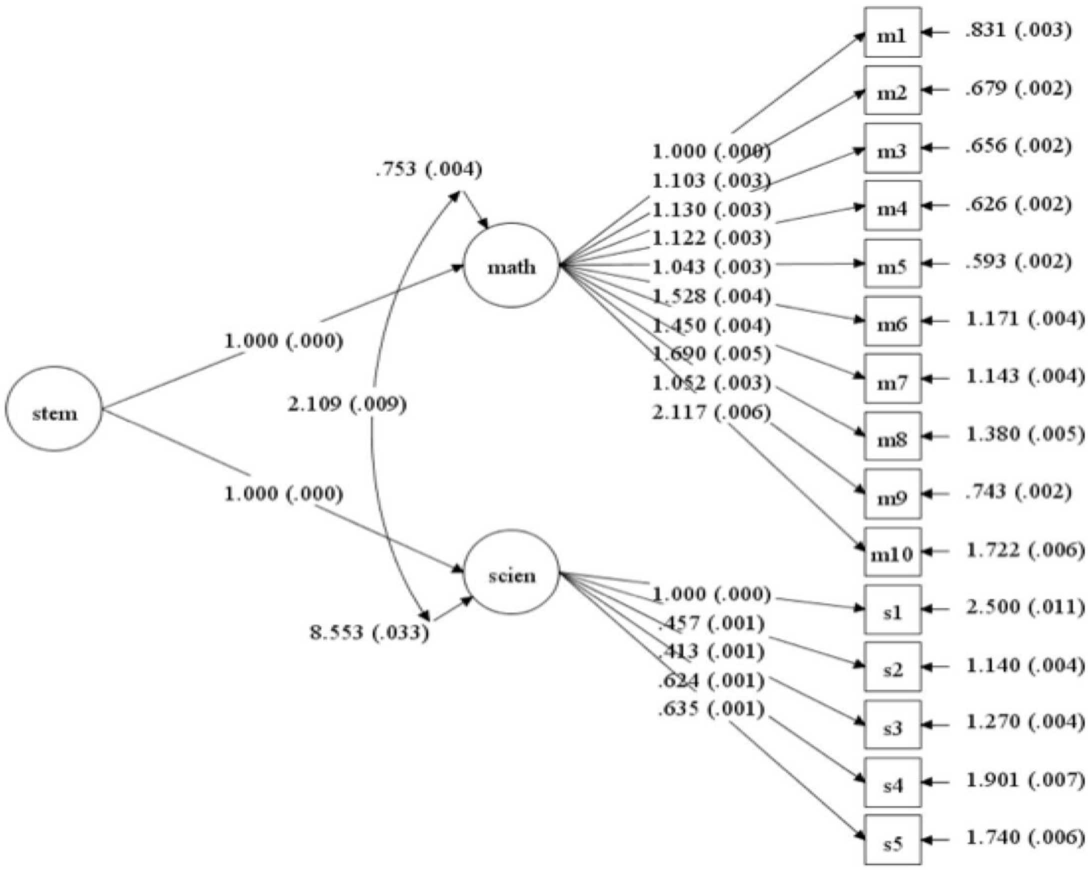

Figure 2. STEM assessment model with science and mathematics objectives

Capraro, Capraro, Oner, & Boedeker, 2015). The present study brings science and mathematics objectives together to constitute a higher order STEM assessment model. The result suggests that science and mathematics objectives together constitute a hierarchical model, and this model yields good model fitness. Furthermore, while the data in this study dealt with very specific content, it is reasonable that regardless of the scope of the content, the model should generically apply to all paired mathematics and science content at any grade level. The robustness of the sample seems to lead to the conclusion that until adequate assessments of technology and engineering concepts begin to be implemented, this hierarchical approach yields useful approximations.

Recent studies emphasized the STEM achievement of students and schools (Bicer et al., 2014; Bicer et al., 2015; Erdogan, 2014; Navruz, Erdogan, Bicer, Capraro, & Capraro, 2014). However, these studies investigated students' science and mathematics achievement separately, although their interest was not solely on students' science and mathematics achievement but rather on their STEM achievement. For example, researchers who tried to understand what factors influenced students' STEM matriculation found that students' STEM college major choice was not directly related to students' overall mathematics achievement.

Later, Wai, Lubinski, and Benbrow (2009) showed that students who have an increased ability in spatial thinking were eventually more likely to pursue STEM careers regardless of proficiency in mathematics. As well as specific areas of mathematics showing a greater relationship to STEM proclivity, it is likely there are specific topical areas in science fields that have a greater effect on STEM interest and achievement. Therefore, if STEM achievement is of interest to researchers, it might be more appropriate to construct a model that covers mathematics and science disciplines jointly.

Another reason for developing a STEM assessment model is that the extant literature already reported a high correlation among students' science and mathematics achievement (Cetin et al., 2015). The theory explored in this study indicated that there was a higher order relationship among those variables (Navruz, Capraro, Bicer, & Capraro, 2015). Science and mathematics objectives together construct a higher order STEM assessment model.

There are many types of STEM schools emerging in the U.S., and these schools specifically integrate engineering and technology into their classrooms (Bicer et al., 2014; Bicer et al., 2015; Erdogan & Stuessy, 2015). In addition, some of them offer specific technology and engineering courses (e.g, Project Lead The Way STEM schools (Tai, 2012)). It is only a matter of time until technology and engineering are assessed, and the money pouring into these programs will push this to the forefront because the public will want to know if they are getting their money's worth from these very expensive programs. Future research about STEM assessment models should consider STEM disciplines jointly, and test the model with science and mathematics objectives as we did in the present study, as well as including estimates of technology and engineering achievement.

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