STEM INTEGRATION IN MATHEMATICS STANDARDS

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Middle school STEM curriculum can serve as a natural progression to rigorous high school level science, technology, engineering, and mathematics classes. Students who experience such a curriculum are more likely to then choose STEM majors in college and ultimately a career in a STEM field. Four middle school mathematics standards were examined for STEM integration: NCTM *Principles and Standards for School Mathematics*, the *Texas Essential Knowledge and Skills (TEKS)*, the *Common Core State Standards for Mathematics (CCSSM)*, and the *Texas College and Career Readiness Standards (TCCRS)*. Instances of integration of 2 or more STEM subjects, real-world problems that would indicate involvement of 2 or more STEM subjects, and project-based learning were coded. The most obvious application of STEM integration was located in the NCTM standards. The CCSSM did not contain STEM integration embedded in the content strands but did include it in mathematical practices. The TEKS contained more references to STEM integration than the CCSSM, and the TCCRS strongly supported integration of subjects, including non-STEM subjects.

STEM (science, technology, engineering, and mathematics) has been defined differently by various researchers (Capraro, Capraro, & Morgan, 2013; Scott, 2009; Wolf, 2008). STEM education has expanded its national presence through initiatives from the National Science Foundation and the Institute for Educational Sciences. Many states have also started statewide STEM initiatives concentrated in PK-12 schools (Herzog, 2010). In addition, STEM has drawn attention from the private sector from the likes of the Gates Foundation, The Houston Endowment, the Society of Manufacturing Engineers, and the American Association of University Women (Berry, Reed, Ritz, Lin, Hsiung, & Frazier, 2004; Dyer, 2004; Toulmin, & Groome, 2007). Additionally, a key report, *Rising Above the Gathering Storm* (National Academies, 2007) initiated by prominent contributors from academia, corporations, and government has acquired substantial attention.

Rising Above the Gathering Storm was written by the Committee on Prospering in the Global Economy of the 21st Century and was announced during a time when there was

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increasing apprehension concerning the global economy of the United States in a competitive world. It focused directly on the need for an increase in workers skillful in technology and science (National Academies, 2007). The committee pointed out shortcomings in mathematics and science education, shortages in research support, and financial guidelines that restrain advancement in technology as reasons for reducing the amount of competent workforce personnel and endangering the U.S. economy.

The Committee on Prospering in the Global Economy of the 21st Century suggested that the U.S. raise "its knowledge-based resources, particularly in science and technology" (National Academies, 2007, p. 4). The endorsements included requests for a larger contingent of mathematics and science educators, extended teacher education programs, advancement of the STEM pipeline throughout elementary and secondary schools, increased research support, and implementation of financial guidelines promoting expansion in science and mathematics. Existing data have shown that achievement of U.S. students in science and mathematics has increased or remained stable, and the present structure has generated a larger number of competent graduates in engineering and science than there were job positions for these graduates to fill (Lowell & Salzman, 2007). No matter how many questions have arisen, there has been agreement that our present society is growing progressively more dependent on STEM subject areas because these content areas are becoming more necessary for those pursuing 21st century jobs. It is also generally agreed that U.S. students were not ranked among the highest achievers in STEM subjects in terms of nationwide benchmarks and worldwide comparisons (Kuenzi, Matthews, & Mangan, 2006).

The STEM areas are viewed as necessary subjects to ensure a monetarily sound national budget; regrettably, however, students have not enrolled in large numbers in STEM subjects. College students have also shunned majors leading to STEM careers. In addition, the involvement of minority students has been underrepresented among STEM majors with regard to ethnicity, gender, and socioeconomic standing in college and careers (Barber, 1995; Capraro, Capraro, & Lewis, 2013; Mullen, 2001; Powell, 1990).

The Association of Middle Level Educators in their document *This We Believe: Keys to Educating Young Adolescents* (National Middle School Association, 2010) highlighted research-based ideas for what is best for 10- to 15-year olds. According to the document students should be: (a) engaged in active, purposeful learning; (b) involved in challenging, exploratory, integrative, and relevant curriculum; and (c) taught by educators who use multiple learning and teaching approaches (Bicer, Capraro, & Capraro, 2014). One effective pedagogical strategy that engages and challenges students is STEM project-based learning (PBL) (Capraro, Capraro, & Morgan, 2013). Middle school students need the 21st century skills (Saavedra & Opfer, 2012) that are an integral part of STEM PBL in order to compete and be prepared in a global world (Han, Capraro, & Capraro, in press). Starting early with these STEM skills provides students an advantage over others. Middle school STEM curriculum can be a natural progression to higher level mathematics, science, and engineering classes in high school, choice of college STEM majors, and ultimately careers in the STEM field (International Technology Education Association, 2009).

National and State Mathematics Standards

The National Council of Teachers of Mathematics (NCTM) was founded in 1920 and has become the largest mathematics education organization in the world. Its board of directors established a commission to help improve school mathematics. In 1987 they drafted a manuscript that resulted in the *Curriculum and Evaluation Standards for Teaching Mathematics* (NCTM, 1989). The document was intended to create an extensive framework to lead reform in school mathematics in the future and to serve as a foundation to improve the teaching and learning of mathematics. Several updates followed, culminating in the *Principles and Standards for School Mathematics* in 2000. In 2006, NCTM published the *Curriculum Focal Points* to identify important topics at each grade level pre-K-8 to further implement the *Standards* (NCTM, 2014).

The State Board of Education is responsible for providing curriculum and instructional materials for public schools in Texas. The *Texas Essential Knowledge and Skills* (TEKS) were developed on the basis of the NCTM *Principles and Standards* as standards for what students should learn and be able to understand at particular grade levels (Texas Education Agency, 2014) and were most recently updated for adoption for the school year beginning in 2012.

The *Common Core State Standards* (CCSS) for English language arts and mathematics were established through a state-led initiative and were "designed to ensure that students graduating from high school were prepared to enter credit bearing courses in two or four year college programs or enter the workforce" (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010, p. 1). Development of the standards included consideration of scholarly research, surveys on skills needed for students entering college or workforce training programs, and findings from Trends in International Mathematics and Science. The middle school and high school standards require students to apply mathematical thinking to real world situations and to think and reason mathematically. Adoption of the standards by individual states was voluntary.

The Texas *Career and College Readiness Standards* (TCCRS) include the areas of English/language arts, mathematics, science and social studies. The TCCRS were designed to represent a full range of knowledge and skills that students need to succeed in entry-level college courses as well as in a wide range of majors and careers. The implementation and dissemination of TCCRS has taken a long time. The TCCRS were created to embody the total scope of knowledge and skills that students need to be successful in beginning-level college classes in addition to an extensive array of careers and majors. According to research, over 80% of jobs in the 21st century will require some post secondary skills (Matthews, 2012). The TCCRS was intended to address the needs for preparing students for postsecondary experiences and careers in addition to high school graduation standards, which basically focused on mastery of basic skills. Even high-quality college prep courses will not prepare a student to pursue certain majors in college. The TCCRS separate themselves from high school standards because they do not focus on content knowledge as an end—the content encourages students to become involved in more profound levels of thinking. These standards focus on "keystone" knowledge and skills. The assumption was that students had already mastered state standards. The final section of the TCCRS contained cross-disciplinary skills that were as important as the four content areas because they contained skills like problem solving across content areas.

METHODOLOGY

There are many different definitions and interpretations of the meaning of "STEM" and what STEM principles include. For the purposes of this study, we confined STEM principles to any content or teaching strategy that involved the integration of two or more areas of science, technology, engineering, and mathematics. Because PBL and/or solving real-life problems almost always contained instructional strategies integrating two or more subject areas, we also included all indicators of these instructional strategies.

The four different middle school mathematics standards (see Appendix) that were examined for STEM integration were the NCTM *Principles and Standards for School Mathe-*

matics, TEKS, *Common Core State Standards for Mathematics* (CCSSM) and TCCRS.

Coding

The coding followed a systematic and organized process. As we read through the four documents from cover to cover, we looked for use of the phrases "real-life problems," "problems … in everyday life," "technology as appropriate," "with and without technology," "connecting mathematics with other domains such as science and art," "with computer," "using materials such as … dynamic geometry software," and other parallel statements. We copied the statements into a spreadsheet. We counted the statements that we selected as indicators of STEM integration.

RESULTS

After examining each of the four documents to locate instances of the integration of two or more STEM subject areas, a table was created and samples of each were included in the Appendix. The complete table, located at aggiestem.tamu.edu/STEMstandards.pdf, demonstrated how STEM learning was infused into the various standards. Phrases from statements that were counted as an instantiation of STEM learning were displayed in Table 1. Table 1 also contained the number of statements that were found referring to real or everyday problems, integration of science (or possibly other subjects), and technology for each of the standards analyzed.

Sometimes the key phrases were embedded in the content, sometimes in the examples, but most often they were located within process standards. Additionally, there were no instances where integration was specifically required in the documents, but there were a few strong statements such as

- "While the use of all types of technology is important, the emphasis on algebra readiness skills necessitates the implementation of graphing technology" (TEKS, Grade 7, 2014, p. 1).
- "Finally, many measurement concepts and skills can be both learned and applied in students' study of science in the middle grades" (NCTM *Principles*, Measurement, 2000, p. 241).
- "Many investigations in middle-grades geometry can be connected to other school subjects. Nature, art, and the sciences provide opportunities for the observation and the subsequent exploration of geometry" (NCTM *Principles*, Geometry, 2000, p. 238)
- "Teachers should regularly ask students to formulate interesting problems … both within and outside mathematics" (NCTM *Principles*, Problem Solving, 2000, p. 258).
- "Clearly, rich problem contexts involve connections to other disciplines (e.g., science, social studies, art) as well as to the real world and to the daily life experiences of middle grades students" (NCTM *Principles*, Connections, 2000, p. 274).
- "If all the middle-grades teachers in a school do their best to connect content areas, mathematics and other disciplines will be seen as permeating life and not as just existing in isolation" (NCTM *Principles*, Connections, 2000, p. 278).

TABLE 1
STEM Integration in Standards

	CCSSM	*TEKS*	*NCTM*	*CCRS*
Real/everyday	7	4	7	2
Integration of other subjects, including science	4	1	12	5
Technology	0	9	23	3

Having been published in 2000, the NCTM *Principles and Standards for Mathematics* was the oldest document examined and analyzed for integration of STEM areas. The most obvious application of STEM integration was in relation to the numerous references to the use of technology, such as graphing calculators and dynamic geometry software or other computer utilities. Simulations were suggested for use in exploring data analysis and probability. In the Introduction to the Standards for Grades 6-8, it was noted, "The understanding of proportionality should also emerge through problem solving and reasoning, and it is important in connecting mathematical topics and in connecting mathematics and other domains such as science and art" (NCTM, 2000, p. 212). In the Number and Operations Standard and the Algebra Standard, there was no specific mention of integrating other subject content. However, in the Geometry strand, "nature, art, and the sciences" were listed as possible arenas in which to experience geometry in our world. In the Measurement Standard, "maps, blueprints, science, and even literature" (p. 245) were given as sources for creation of problems for students to learn more about similarity, ratio, and proportionality. It was suggested that mathematics teachers collaborate with science teachers for students to experience real-life data collection for the Data Analysis and Probability Standard. In the Problem Solving Standard, teachers were encouraged to ask students to "formulate interesting problems based on a wide variety of situations, both within and outside mathematics" (NCTM, 2000, p. 258). As might be expected, the Connections Standard was replete with advice on using other disciplines to find appropriate problems for students to solve and even working with other teachers to develop "integrated units of study" so that academic subjects "will be seen as permeating life and not as just existing in "isolation" (p. 279). The representation standard alluded to collaborative lesson planning and integration of mathematics and science with the statement, "Drawing on what they have learned in science and social studies, they might then…." (NCTM, 2000, p. 284).

The version of the TEKS we analyzed was implemented in September 2012 and is subject to change periodically. In the Introduction to the TEKS for each of the grade levels 5, 6, 7, and 8, technology use was listed as a choice of tools that students utilized to solve problems. One significant difference from the previous version (2009) was that the process standards were more detailed and explicit. For Grades 6, 7, and 8, the underlying processes for the 2009 version specifically stated that students were to "solve problems connected to everyday experiences, investigations in other disciplines, and activities in and outside of school" (p. 2) as well as again listing technology as one of the tools students may choose to use. The 2012 implementation implied such connections by stating that students should be "successful problem solvers" and "use mathematics efficiently and effectively in daily life" (p. 1). Because problems in daily life generally require knowledge of both science and mathematics and/or were best solved with the aid of a technology tool, clearly integrated STEM teaching was not only appropriate but also most effective in helping students develop conceptual understanding.

Although the CCSSM was a relatively new set of standards, the integration of STEM subjects was not mentioned within the content strands. There were instances in the standards for mathematical practice such as "[students] reason inductively about data, making plausible arguments that take into account the context from which the data arose" (mathematical practice 3) (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010, p. 1). In the modeling practice standard it is stated that students will be able to apply the mathematics they have learned "to solve problems arising in everyday life, society, and the workplace" (p. 1). The practice standard for using tools appropriately lists technology such as graphing calculators, spreadsheets, and dynamic geometry software. Although the content standards do not address integration of STEM subjects, most of the examples of problems given were framed in a science context. The phrase "solve real-life and mathematical problems" was found in a variety of places, and we counted those instances (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). We chose to include references to "real-life" problems because such problems almost always involve more than one subject area. For example, when people use mathematics in their lives it is almost always in the context of some scientific, technological, or business application (THECB, 2014).

The TCCRS applied career and college readiness to mathematics in a way that supported STEM integration. The statements related to integration of other subject matters were stronger in this document than the previous documents examined. The following assertions were examples that showed the intent for students to experience integration of STEM content:

- "Mathematics cannot be viewed solely as a series of stand-alone courses or a set of specific skills. It must also be considered as a source of cross-disciplinary knowledge that is essential for success in numerous areas of study" (THECB, 2014, p. 8).
- "Mathematical thinking never occurs in a vacuum; it is always embedded in appropriate content" (p. 8).
- "Use mathematical models to solve problems in areas such as science, business, and economics" (p. 22).
- "Use geometric concepts and properties to solve problems in fields such as art and architecture" (p. 22).
- "Use knowledge gained from other subject areas to solve a given problem" (p. 60).

CONCLUSIONS

The NCTM *Principles and Standards for School Mathematics* laid the foundation over 10 years ago for integration of technology into mathematics. In addition, the *Principles and Standards* introduces the ideas of solving problems embedded in context and content from other subject areas, integrating mathematics and science, and even teacher collaboration for integrated units of study. These were novel ideas to many educators at the time they were written, and movement in that direction has been slow. The CCSSM were disappointing in that they fell short of any real encouragement to integrate subject matter within the content standards, although the process standards alluded to integration and specifically mentioned technology use. To learn more about middle school mathematics teachers' opinions about CCSSM consider *Factors Underlying Middle School Mathematics Teachers' Perceptions about the CCSSM and the Instructional Environment* (Davis, Choppin, & Drake, in this issue). The TEKS have been evolving ever slowly in the direction of full alignment with the NCTM standards. The TEKS were stronger in their STEM language than were the CCSSM, which are used in 43 states in the United States. The TCCRS were even stronger in their endorsement of integration of subjects and even non-STEM subjects. In addition, they presented a different perspective by fitting content into a real-life problem-solving context rather than putting real-life situations into the subject content. These curricular documents and standards seem to be moving in the right direction.

There were some curricular materials and textbooks published more than 10 years ago, about the same time the NCTM *Principles and Standards* were released, that included activities that integrated science concepts and knowledge into mathematics content through real-life problems. Texas Teachers Empowered for Achievement in Mathematics and Science materials for algebra, geometry, and precalculus provide appropriate activities for integrating science concepts. The materials were completed with teacher notes that (a) suggest student collaboration, (b) promote effective questioning for deep conceptual understanding, and (c) support problem solving. One of several high school textbooks with similar characteristics is *Mathematical Models with Applications* (Lege, Bell, Davis, & Nite, 2001). In that book students are encouraged to work collaboratively to present solutions to real-life problems. Two examples of these are (1) determining attributes of an individual whose bones are discovered, using investigation and analysis of data on long bones and height, and (2) presenting information on whether or how restricting water craft might save endangered manatees after analyzing data about water craft registrations and manatee deaths and investigating related issues (Lege et al., 2001). Although they are not slated as such, these problems are examples of STEM PBL, which ideally integrates all four STEM subject areas.

Many stakeholders are seeing the need for full integration of all four areas of STEM to prepare students for the work force and for college. While no one would argue that every teacher should be an expert in every subject, every teacher can benefit from working with other subject area experts in their school to improve the educational setting and curriculum that will foster STEM teaching and learning. There were many references in the TEKS to problem solving and using a problem solving process. The NCTM standards have a problem-solving strand with examples of projects that could be facilitated in the classroom. In the Connections Standard from NCTM and the TCCRS, collaboration of teachers to integrate interdisciplinary studies is briefly discussed. The characteristics of problem solving by students with teacher facilitation as described in the NCTM standards almost describe STEM PBL, which effectively integrates engineering process design with mathematics, science, and technology (Capraro, Capraro, & Morgan, 2013). In order to find and present a solution to an authentic problem, students must work collaboratively and be able to effectively communicate their findings and recommendations. These are among the 21st century skills that students need in order to function successfully in a constantly changing high-tech world for which problems to be solved tomorrow are not even possible to imagine today.

In summary, students exposed to CCSS are lacking in opportunities to experience STEM integrated coursework unless teachers modify their lessons and identify compatible objectives. For ideas of using STEAM to effectively address the Standards for Mathematical Practice, consider *Using Inquiry Principles of Art to Explore Mathematical Practice Standards* (Conley, Douglass, & Trinkley). However, students who are exposed to NCTM standards based curriculum fare much better. NCTM standards contained the greatest number of opportunities for students to experience STEM teaching and learning while not prescribing exact lessons or a STEM dogma. Finally, the TEKS and TCRS are examples of state documents that foster the opportunity for STEM teaching and learning while mostly focusing on real world experiences.

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APPENDIX

Source	*Strand/Topic*	*STEM Indicator*
CCSSM Grade 7	Ratios and Proportional Relationships (Overview)	• Analyze proportional relationships and use them to solve *real-world* and mathematical problems.
CCSSM Grade 7	Expressions and Equations Overview	• Solve *real-life* and mathematical problems using numerical and algebraic expressions and equations.
CCSSM Grade 8	Statistics & probability	• 8.SP.A.3 Use the equation of a linear model to solve problems in the context of bivariate measurement data, interpreting the slope and intercept. *For example, in a linear model for a biology experiment, interpret a slope of 1.5 cm/hr as meaning that an additional hour of sunlight each day is associated with an additional 1.5 cm in mature plant height.*
TEKS Grade 7	Introduction	• 7.a.2 The process standards weave the other knowledge and skills together so that students may be successful problem solvers and use mathematics efficiently and effectively in daily life. The process standards are integrated at every grade level and course. When possible students When possible, students will apply mathematics to problems arising in *everyday life*, society, and the workplace…. Students will select appropriate tools such as real objects, manipulatives, algorithms, paper and pencil, and *technology* and techniques such as mental math, estimation, number sense, and generalization and abstraction to solve problems. Students will effectively communicate mathematical ideas, reasoning, and their implications. • 7.a.3 While the use of all types of technology is important, the emphasis on algebra readiness skills necessitates the implementation of *graphing technology*.
TEKS Grade 8	Mathematical Process Standards	• 8.b.1C select tools, including real objects, manipulatives, paper and pencil, and *technology* as appropriate, and techniques, including mental math, estimation, and number sense as appropriate, to solve problems;
NCTM Principles	Standards for Grades 6–8 – Introduction	• The understanding of proportionality should also emerge through problem solving and reasoning, and it is important in connecting mathematical topics and in *connecting mathematics and other domains such as science and art.*
NCTM Principles	Algebra Standard for Grades 6–8	• A major goal in the middle grades is to develop students' facility with using patterns and functions to represent, model, and analyze a variety of phenomena and relationships in mathematics problems or in the *real world*. With *computers and graphing calculators* to produce graphical representations and perform complex calculations, students can focus on using functions to model patterns of quantitative change. • With a *graphing calculator or computer graphing software*, students can test some conjectures more easily than with paper-and-pencil methods. • Students' examination of graphs of change and graphs of accumulation can be facilitated with specially designed computer software.
NCTM Principles	Geometry Standard for Grades 6–8	• Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, *science,* and *everyday life*. • Students also need to examine, build, compose, and decompose complex two- and three-dimensional objects, which they can do with a variety of media, including paper-and-pencil sketches, geometric models, and *dynamic geometry software*.

(*Appendix continues on next page.*)

Source	*Strand/Topic*	*STEM Indicator*
NCTM Principles (continued)	Geometry Standard for Grades 6-8 (continued)	• Many investigations in middle-grades geometry can be connected to other school subjects. Nature, art, and the *sciences* provide opportunities for the observation and the subsequent exploration of geometry concepts and patterns as well as for appreciating and understanding the beauty and utility of geometry. For example, the study in nature or art of golden rectangles (i.e., rectangles in which the ratio of the lengths is the golden ratio, $(1 + \sqrt{5})/2$) or the study of the relationship between the rigidity of triangles and their use in construction helps students see and appreciate the importance of geometry in our world.
NCTM Principles	Data Analysis and Probability Standard for Grades 6–8	• Because laboratory experiments involving data collection are part of the middle-grades *science* curriculum, mathematics teachers may find it useful to collaborate with science teachers so that they are consistent in their design of experiments. Such collaboration could be extended so that students might collect the data for an experiment in science class and analyze it in mathematics class. • *Computer simulations* may help students avoid or overcome erroneous probabilistic thinking. Simulations afford students access to relatively large samples that can be generated quickly and modified easily. Technology can thus facilitate students' learning of probability.
NCTM Principles	Representation Standard for Grades 6–8	• The use of *graphing calculators or appropriate computer software* can greatly facilitate such an examination and can allow students to see such important relationships as the one between the value of k in the equation $y = kx$ and the slope of the corresponding line. • Drawing on what they have learned in *science* and social studies, they might then make recommendations for reducing the flow of paper into landfills or incinerators.
TCCRS Mathematics Standards	Understanding and Using These Standards	• Mathematical thinking never occurs in a vacuum; it is always embedded in appropriate content. The use of *technology* is an instructional decision that facilitates the learning of mathematical concepts and processes.
TCCRs Mathematics Standards	Functions	• VII. C.2.c Identify *real world* situations that can be modeled by functions (e.g., situations in science, business, economics).
TCCRS Mathematics Standards	Connections	• X. A.2. Connect mathematics to the study of *other disciplines*. • a. Use mathematical models to solve problems in areas such as *science*, business, and economics. • b. Use applications of mathematics (e.g., carbon dating, exponential population growth, amortization tables). • X. B.2. c. Apply known mathematical relations (e.g., Ohm's Law, Hardy-Weinberg Law, rule for continuously compounded interest) to solve *real world* problems.