STEM Integrations and Teachers' Role in This Process

Feral Ogan-Bekiroglu
Marmara University

Fatma Caner
Marmara University

What is STEM?

Living fulfilling and meaningful lives in the 21st century requires individuals to have capabilities such as deep, useable knowledge of scientific and engineering ideas and scientific and engineering practices, as well as the creative, problem solving, and communication skills and judgment to apply STEM ideas (Krajcik & Delen, 2017). It is clear that there is a shift in the way science education is being conceptualized, and such integration of STEM disciplines at the K-12 level offers students an opportunity to experience learning in a real-world, multidisciplinary context (Dare, Ellis & Roehrig, 2018).

In short, STEM is accrued knowledge of science, technology, engineering and mathematics as separate but related fields. However, there are many definitions of STEM. For example, Tsupros, Kohler and Hallinen (2009) define STEM as "an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons in contexts that make connections between school, community, work, and the global enterprise" (p. 2). Moore, Johnson and Peters-Burton (2015) define STEM as "the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies" (p.24). According to Krajcik and Delen (2017), a richer, more productive manner of thinking is to define STEM as an integration of science, technology, engineering and mathematics to focus on solving pressing individual and societal problems. Kelley and Knowles (2016) on the other hand, state that there is a need for a conceptual framework beyond a simple definition of STEM education. They explain STEM education as a process approach or a process philosophy involving two or more STEM disciplines, including engineering and mathematical thinking, where the engineering design process is used to solve real-life problems with scientific inquiry (Kelley & Knowles, 2016). Bybee (2013), whose definition was adopted for this study, leaves STEM ill-defined and suggests that the most accurate definition may come from one's personal context and needs and explains the perspectives of nine different STEM education through visual presentations.

STEM Integration

Teaching STEM disciplines through integration is appropriate with STEM purposes.

Wang (2012) reviewed the literature and pointed out that integrated curriculum, with its ability to incorporate information from different fields, has been shown to increase students' involvement, motivation, problem-solving skills, and cooperative learning skills. The "Integrated STEM Education" framework was presented in 2014 by the National Academy of Engineering and the National Research Council. Integrated STEM education provides authentic contexts for learning and enables students to make connections among the STEM disciplines, and it also supports "building knowledge and skill both within the disciplines and across the disciplines" (NAE & NRC, 2014, p. 5). Objectives of integrated STEM education;

- STEM literacy
- 21st century competencies
- Preparing for work in STEM areas
- Stimulation of students in STEM disciplines and providing links.

According to the committee, the results of integrated STEM Education are;

- Learning and success
- 21st century competencies
- Better understanding of STEM content
- Increase pedagogical content knowledge and STEM content knowledge
- The development of STEM identity
- The development of the ability to make connections between STEM disciplines.

Researchers have conceptualized and presented perspectives on what they think integrated STEM is. Honey, Pearson and Schweingruber (2014) provide a basic definition of integration as "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines" (p. 52). Integrated STEM has been described as integrating science, technology, engineering, and mathematics concepts in ways that reflect the practice of STEM professionals to encourage students to pursue STEM professions (Breiner, Harkness, Johnson, & Kohler, 2012).

A more comprehensive perspective on STEM integration is featured in work of Vasquez, Sneider and Comer (2013), where different forms of boundary crossing are displayed along a continuum of increasing levels of integration, with progression along the continuum involving greater interconnection and interdependence among the disciplines. According to Vasquez et al. (2013), there are four levels of integration. In disciplinary integration, students learn concepts and skills separately in each discipline. In multidisciplinary integration, students learn concepts and skills separately in each discipline but within a common theme. In interdisciplinary integration, students learn concepts and skills from two or more disciplines that are tightly linked so as to deepen knowledge and skills. Finally, in transdisciplinary integration, by undertaking real-world problems or projects, students apply knowledge and skills from two or more disciplines and help to shape the learning experience (Vasquez et al., 2013).

On the other hand, Moore et al. (2014)'s STEM integration framework includes six major tenets for successful STEM education: (1) a motivating and engaging context, (2) the inclusion of mathematics and/or science content, (3) student-centered pedagogies, (4) an engineering design, (5) an emphasis on teamwork and communication, and (6) learning from failure through redesign. Roehrig, Wang, Moore and Park (2012) define STEM integration as the "merging of the disciplines of science, technology, engineering, and mathematics in order to help teachers to: (1) deepen student understanding of STEM disciplines by contextualizing concepts, (2) broaden student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts, and (3) increase student interest in STEM disciplines to expand pathways for helping STEM fields" (p.35).

Bybee (2013) offers a range of models to describe STEM education from various educational perspectives, ranging from STEM as a replacement acronym for science or mathematics to STEM as representing true integration across all four fields. Bybee presents eight approaches for integration with a focus on STEM education. In these approaches, STEM refers to (a) science (or mathematics); (b) both science and mathematics; (c) science and the incorporation of technology, engineering, or mathematics; (d) a quartet of separate disciplines of science, mathematics, engineering, and technology; (e) science and mathematics that are connected by a technology or engineering program; (f) coordination across disciplines; (g) combining two or three disciplines; (h) complementary overlapping across disciplines; (i) a transdisciplinary course or program. He also argues that integration cannot be accomplished quickly and requires development of a plan of action to improve STEM education. Bybee demonstrates that this integration can be done in different ways as STEM 1.0 (single discipline), STEM 2.0 (two disciplines), STEM 3.0 (three disciplines) and STEM 4.0 (four disciplines) in creating the STEM curriculum. He states that these integrations can be done in five different ways such as coordinating, complementary, associating, linking and integrating. Bybee's integration model was obtained for this study.

Teachers' Role in STEM Integration

Learning science through engineering is challenging. The biggest problem in integrating the engineering design process into the learning environment was the inability of the integration of science and mathematics effectively in the context. Teachers need to hold certain skills and knowledge so that they can integrate technology and engineering concepts into their classroom practices (Akaygun & Aslan-Tutak, 2016). Therefore, the role of the teacher is critical in this process. Since high-quality teachers are instrumental in positively affecting students' attitudes, motivation, and achievement, providing teachers with adequate support via effective professional development is vital to ensure our students are adequately prepared to enter our increasingly technologically-driven world as "STEM literate" citizens (McDonald, 2016). Yet, often integrated STEM instruction is not an intentional part of teacher education programs, and most pre-service and in-service teachers lack adequate integrated STEM exposure (O'Brien, Karsnitz, Sandt, Bottomley & Parry, 2014).

Although pre-service STEM teacher education should include STEM content, pedagogy, and conceptualization, the literature suggests no leading conception of STEM education, and little is known about teachers' thinking about STEM (Radloff & Guzey, 2016). One of the biggest educational challenges for K-12 STEM education is that few general guidelines or models exist for teachers to follow regarding how to teach using STEM integration approaches in their classroom (Wang, Moore, Roehrig & Park, 2011). Therefore, for effective integration it is helpful to know how pre-service teachers are conceptualizing and understanding STEM education.

Literature Review about Teachers' Beliefs, Conceptions and Perceptions

How teachers conceptualize, interpret, and subsequently enact STEM content and engineering impacts the learning experiences they provide in their classrooms (Diefes-Dux 2014). However, there are only a few research done in this area. For example, Wang et al. (2011) conducted a multi-case case study with three middle school teachers to gain a better understanding of teachers' beliefs about and perceptions of STEM integration, and to examine the connections between beliefs about and perceptions of STEM integration and teachers' classroom practices. They obtained the following results: First, the problem solving process was a key component to integrate STEM disciplines. Second, teachers in different STEM disciplines had different perceptions of STEM integration and that leaded to different classroom practices. Third, technology was the hardest discipline to integrate in these cases. And finally, teachers were aware of the need to add more content knowledge in their STEM integration. Siew, Amir and Chong (2015) investigated the perceptions of 25 pre-service and 21 in-service Malaysian science teachers in adopting an interdisciplinary project-based STEM approach to teaching science. Data on teachers' perceptions were captured through surveys, interviews, open-ended questions and classroom discussion before and at the end of the eight-hour workshop. They indicated that STEM professional development workshops could provide insights into the support required for teachers to adopt innovative, effective, project-based STEM approaches to teaching science in their schools.

In their study, Guzey, Moore and Harwell (2016) worked with 48 teachers by implementing conversion mixed method design. The teachers participated in a year-long professional development program on STEM integration, and they designed 20 new engineering design-based STEM curriculum units. Comparisons among the STEM units showed that mathematics integration and communicating mathematics, science, and engineering thinking were not found to strongly contribute to the overall quality of the STEM units (Guzey et al., 2016). Radloff and Guzey (2016) explored 159 pre-service STEM teacher conceptions of STEM education by using an open-ended survey. Their study yielded many findings and future directions. High variation existed in both textual and visual conceptions of STEM education, not readily connected with teacher experiences. Although there were commonalities in responses (for example Interconnected visualizations), new visualizations were found as well (Radloff & Guzey, 2016). Dare, Ellis and Roehrig (2018) designed a phenomenological multiple case study to understand nine science teachers' first-time experiences in implementing integrated STEM curricular units in their middle school physical science classrooms. Their results showed three distinct cases of STEM integration throughout curriculum implementations as low, medium, and high degrees. They revealed three themes that varied across teachers' experiences: the nature of integration, choosing between science and engineering, and student engagement and motivation. More research is needed to identify teachers' beliefs about and conceptions of STEM to provide professional development for teachers about STEM integration.

References

Akaygun, S., & Aslan-Tutak, F. (2016). STEM images revealing stem conceptions of pre-service chemistry and mathematics teachers. *International Journal of Education in Mathematics, Science and Technology, 4*(1), 56-71.

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3–11.

Bybee, R. (2013). *The case of STEM education: Challenges and opportunities*. Arlington, TX: NSTA Press.

Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education, 5* (4)

Diefes-Dux, H. A. (2014). In-service teacher professional development in engineering education: Early years. In S. Purzer, J. Strobel and M. E. Cardella (Eds.), *Engineering in precollege settings: Synthesizing Research, Policy, and Practices.* West Lafayette, IN: Purdue University Press.

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building Up STEM: An Analysis of Teacher-Developed Engineering Design-Based STEM Integration Curricular Materials. *Journal of Pre-College Engineering Education Research (J-PEER), 6*(1), Article 2.

Honey, M., Pearson, G., & Schweingruber, A. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11).

Krajcik, J., & Delen, I. (2017). How to support learners in developing usable and lasting knowledge of STEM. *International Journal of Education in Mathematics, Science and Technology, 5*(1), 21-28.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM Integration: Teacher Perceptions and Practice. *Journal of Pre-College Engineering Education Research (J-PEER), 1*(2), Article 2.

McDonald, C. V. (2016). STEM Education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. *Science Education International, 27* (4), 530-569

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In J. Strobel, S. Purzer and M. Cardella (Eds.), *Engineering in precollege settings: Research into practice*, (pp. 35–59). West Lafayette, IN: Purdue University Press.

Moore, T. J., Johnson, C. C., & Peters-Burton, E. E. (2015). The need for a STEM road map. In C. C. Johnson, E. E. Peters-Burton, and T. J. Moore (Eds.), *STEM road map: A framework for integrated STEM education* (pp. 3–12). New York, NY: Routledge.

National Academy of Engineering and National Research Council. (2014). STEM Integration in K–12 Education: Status, Prospects, and an Agenda for Research. Washington, DC: The National Academies Press.

O'Brien, S., Karsnitz, J., Sandt, S., Bottomley, L., & Parry, E. (2014). Engineering in preservice teacher education. In S. Purzer, J. Strobel and M. E. Cardella (Eds), *Engineering in pre-college settings: synthesizing research, policy, and practices* (pp. 277–300). West Lafayette, IN: Purdue University Press.

Radloff, J., & Guzey, S. (2016). Investigating Preservice STEM Teacher Conceptions of STEM Education. *Science Education Technology, 25*, 759–774.

Roehrig, G. H., Wang, H. H., Moore, T. J., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31-44.

Siew, N. M., & Amir, N., & Chong, C. L. (2015). The perceptions of pre-service and in-service teachers regarding a project-based STEM approach to teaching science. *Springer Plus, 4*(8)

Tsupros, N., Kohler, R., & Hallinen, J. (2009). *STEM education: A project to identify the missing components*. Intermediate Unit 1. Center for STEM Education and Leonard Gelfand Center for Service Learning and Outreach, Carnegie Mellon University, Pennsylvania.

Wang, H. H., Moore, T. J., Roehrig, G. H., Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research, 1*(2), 1–13.

Wang, H. H. (2012). *A New Era of Science Education: Science Teachers' Perceptions and Classroom Practices of Science, Technology, Engineering, and Mathematics (STEM) Integration*. Unpublished doctoral dissertation, The University of Minnesota, Minneapolis, MN.

Vasquez, J., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, grades 3–8: Integrating science, technology, engineering, and mathematics*. Portsmouth, NH: Heinemann.