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Greater than the Sum of its Parts: Centering Science within Elementary STEM Education

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CHAPTER 14

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INTRODUCTION: WHY STEM LEARNING?

Reform efforts in K-12 STEM (that is, Science, Technology, Engineering, and Mathematics) education have been prevalent in the past decade to respond to the future needs related to the global STEM workforce (National Academy of Engineering and National Research Council, 2014). Locally and throughout the United States, science receives relatively little emphasis in elementary grades. A large-scale national survey found that an average of only 20 minutes per day are spent teaching science in elementary, compared to 87 minutes for reading/language arts and 58 minutes for mathematics (Plumley, 2019). The survey also found that elementary teachers felt less prepared to teach science, engineering, and coding, while findings from a different survey indicated that United States pre-service elementary teachers agreed that STEM education was important at the elementary level (Madden et al., 2016). It is prudent to re-envision teacher

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preparation programs, so the next generation of teachers is competent and confident to teach STEM in a K-12 setting in ways that excite future generations of students for STEM-related careers (Atkinson and Mayo, 2010; Chen et al., 2021).

Early exposure to STEM learning increases student's foundational knowledge in STEM (Chen, 2011), develop students' critical thinking skills and literacy (Paugh and Wendell, 2021), and increases students' motivation and interest in STEM career fields (Nesmith and Cooper, 2020; Wang, 2013). Integrating across STEM subjects has shown promise as a strategy for improving students' knowledge in STEM disciplines, connecting, and transferring knowledge among STEM disciplines, developing creativity and technological skills, and cultivating positive attitudes and interest in STEM subjects (for example, Century et al., 2020); Martín-Páez et al., 2019; Miller, 2019). When STEM learning experiences are incorporated into the teacher preparation programs, pre-service teachers have a deeper understanding of integrated STEM instruction (Pimthong and Williams, 2021) and are more likely to incorporate them in their future lesson plans (Maiorca and Mohr-Schroeder, 2020). Reform efforts include rethinking ways in which pre-service elementary teachers (PSTs) are currently prepared within teacher preparation programs (Darling-Hammond and Bransford, 2007). In response to this challenge, our team engaged in the process of conceptualizing STEM Integration and redesigning Integrated STEM curriculum for our STEM Semester.

Conceptualizing STEM Integration

For our reform efforts, the fundamental question to consider was, "What is STEM learning, or what should count as STEM learning?" The different models and definitions for Integrated STEM education range from STEM disciplines traditionally taught as separate and distinct content areas to integration among the four STEM disciplines (NAE and NRC, 2014; Stohlmann et al., 2012). Teacher educators are often challenged to design STEM learning experiences within teacher preparation courses that prepare for the reality of classrooms while presenting pedagogical alternatives (Corp et al., 2020). Many researchers, for instance, Roehrig et al. (2012) distinguish between content and context integration of STEM. Content integration requires the blending of knowledge from different content fields into a single curricular activity or unit to build a collective knowledge of STEM from multiple content areas (Roehrig et al., 2012; Wang et al., 2011) while context integration, "primarily focuses on the content of one discipline and uses contexts from others" to make the content more relevant (Roehrig et al., 2012, p. 9). Most researchers conclude that STEM integration should involve the merging of some or all the STEM disciplines to solve real-world problems (Moore et al., 2020; Rinke et al., 2016).

Our conceptualization of STEM integration stems from (1) Dewey's work (1938) that highlights learning as an active process that involves students engaged in experiences situated in and connected to the *real world* and, (2) ideas based on social constructivism developed by Vygotsky (1978) that emphasize learning via social interactions among individuals within a social setting. Constructionist theory (Ackermann, 2001; Harel and Papert, 1991; Papert, 1980) also framed learning experiences in the integrated STEM semester. Teaching Integrated STEM calls for pedagogies that promote active learning that engages students in social interactions while working collaboratively in teams (Moore et al., 2014), and knowledge that is constructed via social discourse (Stohlmann et al., 2012). Other pedagogies that are fundamental to conceptualizing STEM learning are inquiry-

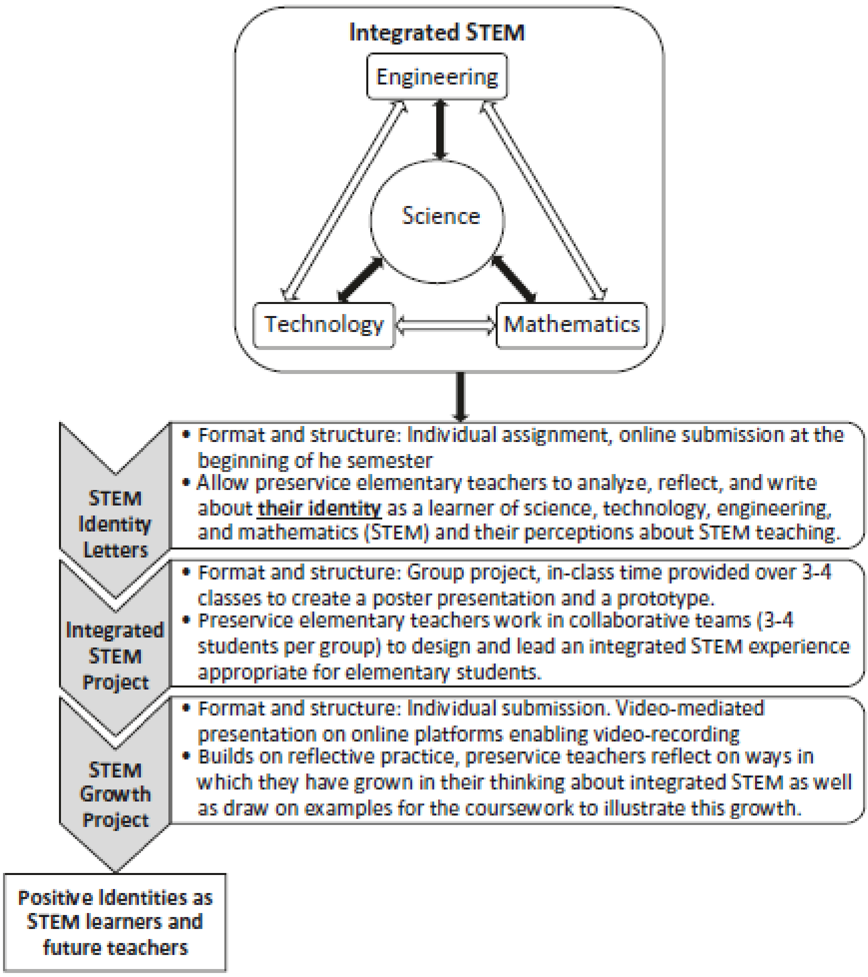

Figure 1. Framework and shared assignments for integrated STEM for curriculum reform curriculum design and STEM pathways (shared assignments) across multiple courses within the STEM Semester as explained in the subsequent sections.

based and hands-on strategies promoted in the *Next Generation Science Standards* (Bybee, 2009); NGSS Lead States, 2013), problem-based learning that involves a problem to solve (Shaughnessy, 2013) and connections to real-life experiences (Kelley and Knowles, 2016).

In leading our curriculum reform effort, we draw upon the viewpoint that STEM curriculum must involve both content and context integration. Figure 1 illustrates our conceptual framework for re-structuring our elementary STEM Semester. Our framework positions science at the center placing emphasis on scientific inquiry (Kelley and Knowles, 2016). Integrated STEM education has strong ties to inquiry processes allowing students to formulate questions, participate in investigations that facilitate engineering design, and integrate technology and mathematics to design solutions to complex real-world problems (Kennedy and Odell, 2014; Moore and Smith, 2014). Figure 1 depicts the interconnected relationship between disciplines where engineering, technology, and mathematical knowledge provide a context for meaningful science learning and vice versa. The framework served as a guide to inform our Integrated STEM curriculum design and STEM pathways (shared assignments) across multiple courses within the STEM Semester as explained in the subsequent sections.

STEM Curriculum Reform: A Constant Flux

The need to emphasize STEM subjects in elementary teacher preparation prompted curriculum reform to create the STEM Semester within an elementary education program at a large mid-western university. The program typically admits 70–80 PSTs per semester. This effort was led by a multi-disciplinary team of STEM educators and researchers including faculty and graduate students in science and engineering education, mathematics education, and technology education. Prior to this reform effort, the elementary teacher education program was organized in four semesters, taken sequentially after admission to the professional phase of the program: Math Block, Literature Block, "Methods" Block, and Student Teaching. The Math Block included integrated mathematics content and mathematics methods courses, a 1.5-day per week practicum in a local elementary school, as well as an innovative learning technologies course, and a course and associated practicum focused on English Language Learners (ELL). At that time, the science methods course was part of the "methods block," and was not associated with a field experience. Math Block, initially developed with support from National Science Foundation (NSF) (DUE #9981106), offered a successful model of collaboration among instructors and departments. Math content and methods courses were scheduled back-to-back, in the same classrooms, with instructors frequently sitting in on one another's courses, and students cohorted by sections. A unified syllabus and key assignments were shared between the math content, math methods, and practicum courses (Heaton and Lewis, 2011).

Extending the existing Math Block logic, we used a design process to reimagine the STEM Semester to integrate across the three methods courses: Math methods, Science methods, and Innovative Learning Technologies (ILT). The process included:

- Challenging pre-existing beliefs and status quo situated within each discipline,
- Reaching common ground with a shared understanding of STEM integration as a dynamic process,
- Strategizing the flow of STEM learning across various courses within the program,
- Implementing the curriculum,
- Continuing reflection and revision.

Faculty and graduate student instructors met during the summer prior to the first STEM Semester iteration to compare existing course content, find areas of potential overlap among classes, and create a flexible framework that would allow a mutually agreeable balance of disciplinary content and integrated STEM content. This approach included shared assignments focused on developing positive identities as STEM learners and future teachers, and embedded thematic topics that would be integrated across the three methods courses (see Figure 1 above for more details related to structure and format of shared assignments).

The team of course instructors collaboratively designed, implemented, and assessed three shared assignments that complemented the discipline-based lesson plans and assignments students did within individual courses. The shared assignments (Figure 1) included STEM identity letters, an integrated STEM project, and a STEM growth presentation. STEM identity letters asked PSTs to present their initial definition of STEM and reflect on their identities as learners and future teachers of STEM subjects. The integrated STEM project was an opportunity for PSTs to work in teams, design an integrated STEM learning experience for elementary students, and reflect on what they learned from that experience. The culminating semester project was a STEM growth presentation for which PSTs selected and showcased artifacts of their work to support reflections about their development as learners and teachers of integrated STEM and its constituent disciplines. During the inaugural STEM semester, a coding and robotics theme was integrated across courses and a second theme of sustainability was added the following semester. These thematic pathways are detailed later in this chapter.

The design of the STEM Semester was intentionally flexible to encourage disciplinary autonomy within courses, anticipate changes in instructors over time, allow for research-based best practices, and amplify the assets and priorities each instructor brings to their course. STEM Semester instructors continued to meet regularly to collaborate around shared assignments, STEM-themed class activities, and PST needs and concerns. While the initial structure of the STEM Semester remains, the shared assignments undergo revision each semester and the STEM themes are implemented differently by new instructors within and across courses. The COVID-19 pandemic tested the flexibility of the STEM Semester in a unique way, but instructors collaboratively rose to the challenge and continued to implement the STEM Semester framework, often with alternative activities or revised assignments.

The STEM-Themed Pathways

The integrated STEM semester drew upon existing models of STEM integration (for example, Kelley and Knowles, 2016; Moore et al., 2014) by connecting STEM content areas within communities of practice, defining STEM as an effort to integrate some or all STEM content areas, and making purposeful connections to enhance learning. Playing, creating, and minimalist teaching approaches maximized PSTs' opportunities to learn through exploration, in turn, preparing them to do so with elementary students.

Cross-Course STEM Themes

Two themes were integrated across the STEM Semester courses: robotics/coding and sustainability. The robotics theme was emphasized primarily in the ILT course and reinforced in mathematics and science methods courses. PSTs also reflected individually on how each tool could be aligned with STEM standards and instruction in elementary classrooms. The sustainability module provided a model of collaborative STEM integration within and across courses, culminating in an engineering design challenge. Unlike shared assignments which involved out-of-class work, STEM themes occurred primarily during scheduled class time.

Robotics and Coding. The robotics theme was introduced with a block-based coding activity in Scratch that aligned with elementary mathematics standards. PSTs learned introductory coding principles and developed a foundation for engaging with educational robotics throughout the semester. Rather than emphasizing one or two robots/coding tools, PSTs explored several robots and coding tools throughout the semester. In mathematics methods courses, PSTs learned to use BeeBots (see Figure 2, left side) for engaging young learners in coding and algorithmic thinking while learning about connecting multiple mathematical representations.

Figure 2. Using BeeBots to Connect Mathematical Representations (left side) and Testing Flood Mitigation Designs on an Enviroscape Floodplain Model (right side).

science methods courses, PSTs learned to program and use micro:bits as tools for collecting moisture, temperature, and light data in an environmental science inquiry activity and designed their own NGSS-aligned science lessons using micro:bits. During the ILT course, PSTs engaged in structured. In play with Cubelets, Ozobots, Edison bots, and Osmo and discussed connections with mathematics and science standards.

PSTs also learned to code and use Dash bots in an integrated STEM activity during the mathematics methods course (Figure 2). PSTs designed a 120 cm path (Goo, 2019) within a science context of their choice (for example, zoo, solar system, water cycle), programmed Dash to give a tour with at least five stops (each identifying science content, distance traveled, and fraction of the whole length), and demonstrated Dash's tour with classmates. Similarly, PSTs learned to use Sphero robots during an ILT class by designing a maze, coding Sphero to drive through the maze, and aligning to the area and perimeter standards (Figure 2). PSTs could use any of the educational robotics in their Integrated STEM Projects and although most students did not elect to do so, some teams incorporated BeeBots, Ozobots, and Dash bots.

Sustainability. The second STEM Semester theme resulted from instructors' participation in a university-wide Sustainability Curriculum initiative. STEM Semester instructors used a multi-disciplinary approach, incorporating related science content in science methods, math content during mathematics methods, and technology and engineering during multiple ILT class sessions. The components of the project were purposefully sequenced within and across courses and drew upon published materials from the Interdisciplinary Teaching about Earth for a Sustainable Future (InTeGrate) project (DeBari et al., 2020) and Water Warriors design challenges (Jason Learning, 2019).

In science methods, PSTs learned about the hydrologic cycle, aquifers, floodplain management, and common misconceptions while drafting 5E lesson plans (Bybee, 2009) and engaging with a university hydrologist. In a subsequent mathematics methods class, PSTs used authentic data, interpreted graphs of precipitation and river discharge, calculated recurrence intervals, used probability to define 100- and 500-year floods, and interpreted floodplain maps and graphs. In the ILT class, PSTs visited a maker space to scale and 3D-print house models and designed mitigation strategies to protect their houses from flooding on an Enviroscape floodplain model (see Figure 1, right side). PSTs then placed their 3D printed houses at assigned locations on the Enviroscape. To test and discuss the effectiveness of PSTs' flood mitigation design strategies, a civil engineer who specialized in surface water hydrology and watershed management joined the ILT classes. Two types of flooding were approximated on the Enviroscape. First, water was sprinkled over the model to mimic rain over a continuous period. Then, water was poured rapidly, mimicking the deluge of a dam break (a phenomenon that had recently occurred in the region). The engineer helped students interpret the effectiveness of their strategies and compare their designs with strategies used in the real world. Locations of houses on the model also impacted the effectiveness of PSTs' designs, intentionally inviting discussions of resources, power, privilege, and justice in the context of the project.

Evidence of Success with the STEM Semester

This section represents themes that resulted from preliminary qualitative analysis of PSTs' ($N = 76$) perceptions of STEM at the beginning and end of the STEM Semester. We discuss: (1) initial themes from the STEM identity letters that PSTs wrote at the beginning of the semester documenting their personal and professional experiences with science/STEM and their perceptions about STEM teaching and learning and (2) final themes from focus-group video sessions on PSTs' experiences with the integrated STEM project and individual video-mediated STEM growth project presentations (Table 1).

Initial Perceptions of STEM

At the beginning of the semester, we found that PSTs had naïve conceptions of STEM likely due to a lack of exposure to STEM learning in K-12

Table 1 Sample coding scheme for themes at the beginning and end of the semester

Themes	*Code*	*Sample Excerpts*
Beginning of the semester		
Naïve conceptions about STEM integration	Intimidating; don't know much about STEM	I think people can be intimated by the acronym STEM. I know STEM stands for science, technology, engineering, and mathematics; however, there is much more than just that that I do not know
Lack of confidence in STEM content or STEM teaching	Not sure to incorporate different components into one lesson	I am not so sure about how I would incorporate so many different components [science, technology, engineering, and mathematics] into one lesson
STEM stereotypes	Only for guys, rare to see a woman in STEM	When I think of STEM, I think of a lot of stereotypes and stigmas. I think about how STEM is "only for guys," or how rare it is to see a woman in STEM
End of the semester		
Increased value and importance for integrated STEM in K–5 classrooms	Come together, integrated, skills and interest in STEM	Four different pillars need to come together and be integrated so that students can develop skills and an interest in STEM that can help them understand how our world works and how to adapt to it
Shifting away from biases; STEM for ALL learners	Encourage every student, creative, can do it	It is important for teachers to encourage each and every one of their students to think critically in these subjects. I also think STEM can be creative and therefore, any student can do it
Increased confidence in planning and designing integrated STEM lessons	Confident, integrate into one lesson	I feel confident in my ability to integrate all of these subjects into one lesson effectively, more so than before

classrooms. Unsurprisingly, when responding to "what STEM means to them," a majority of PSTs stated that they did not know what STEM means and indicated little or no exposure to STEM prior to college. As one PST mentioned, "Growing up we didn't learn much of STEM specifically, it was mostly just math with a very few basic science lessons." Further, negative dispositions toward STEM disciplines resulted in low personal affinity or interest toward creating STEM lessons and STEM teaching overall. For instance, a PST wrote, "STEM is a hard thing to wrap our heads around. It has to do with science, technology, engineering, and mathematics. These are some hard subjects that do not come easy to many people." We also found that PSTs demonstrated assumptions about societal stigmas and gender bias: "I think of 'left brain' people succeeding in STEM. More than anything, I think teachers need to encourage girls to participate in STEM."

Change in Perceptions

We found that the STEM Semester experiences helped PSTs recognize the value and importance of Integrated STEM in elementary classrooms and develop positive attitudes toward Integrated STEM instruction. As one PST mentioned, "At the beginning of the semester I thought that Integrated STEM was science and math while playing games on the computer. Now, after going through various courses, I would say STEM is any educational tool, lesson, curriculum, or activity that has a basis in one or more of the fields of math, science, technology, and engineering." Furthermore, after engaging with the STEM Semester curriculum, we noted a shift in PSTs' perceptions. Students began to view STEM as critical for all students, not just left-brain individuals and males. One PST noted, "[STEM is] especially important for all young students, but especially young girls and racially diverse students who may feel excluded." Most PSTs explicitly talked about the importance of real-world STEM connections, noting that STEM lessons can provide young children "a variety of learning opportunities put together to teach new perspectives." PSTs realized that STEM helps student build new skill sets as STEM allows "students and educators to get creative with their work. They get to think, build, be a leader, try new things, and learn." We also found that PSTs' confidence in integrated STEM planning and lesson design increased as hey completed the STEM Semester. For instance, one PST acknowledged the interconnectivity between STEM disciplines to create a lesson:

> *Before this semester, STEM classes were individual and lived on their own, separately. Math was math, science was science, and they just stayed that way. This semester really taught me that these classes can join forces to create a really successful lesson.*

Challenges Faced and Lessons Learned

No effort to renovate a teacher preparation program comes without challenges. Unsurprisingly, PSTs reported concerns considering their first exposure to integrated STEM instruction. We describe these challenges and lessons learned with an aim to provide meaningful insights that maximize student learning in STEM methods courses.

- Increased time commitment in designing Integrated STEM lessons. We recognize that there is an increased time commitment and accountability for PSTs to brainstorm ideas, create Integrated STEM lessons that integrate two or more disciplines, and coherently apply knowledge learned from different STEM methods courses. Having patience and lending seamless support to students is the key to students' success in achieving this challenging task. This can be well achieved by providing time within classrooms for students to work on projects rather than out-of-class work where immediate feedback is not available.

- Collaborating with peers who have varied perceptions and affinity toward STEM subjects. Pre-service teachers arrive in methods courses with varied beliefs and perceptions about STEM subjects owing to their prior experiences in science (Knaggs and Sondergeld, 2015) or other disciplines in STEM (Huziak-Clark et al., 2015). Working on collaborative projects where STEM interest, motivation, and comfort level differs from individual to individual can be intimidating. This is quite understandable, because we found PSTs were concerned about their lack of STEM background knowledge. Continuous support and mentoring are needed throughout the program so that PSTs can overcome fear as they continue to engage in collaborative group tasks such as Integrated STEM lesson designs (Menon and Sadler, 2016, 2018).

- Negotiating between how STEM was taught to them (personal prior learning experiences) while learning new pedagogies they are expected to teach in the future. It is important to realize that most students learned STEM disciplines in a traditional way where each of the disciplines was taught in a discrete way. New pedagogies to deliver integrated STEM instruction can put PSTs under pressure while they are negotiating with their own personal teaching philosophies. Creating a classroom environment and culture where their ideas are valued, providing the time they need to process the "conceptual change" encompassing STEM teaching, and offering opportunities to ask questions freely will help PSTs value STEM instruction (Delahunty and Kimbell, 2021; Ryu et al., 2019).

Take-Aways for STEM Educators

Thomas Kuhn, in his writings about scientific revolutions (1962), posited that "paradigm shift" comes with its own challenges and the process of change may not be straightforward but achievable. Based on the experiences described throughout this chapter, we provide a set of recommendations for future teacher educators, who as a group of champions coming together, are willing to restructure their elementary education programs for STEM integration.

Recommendation 1. *Social discourse to develop a shared understanding of Integrated STEM among STEM educators*. In our experience, social discourse among the team has strengthened our collective understanding of Integrated STEM. Although everyone has a busy schedule, meeting biweekly as a STEM Semester team allowed open communication about the steps needed to ensure seamless implementation of shared assignments, reflect critically on our implementation of the curriculum, revise our shared activities and assessments, and brainstorm ideas to address any concerns students have while engaged in this experience.

Recommendation 2. *Negotiating roles and responsibilities amongst the team of STEM educators to ensure the seamless integration of STEM disciplines*. We believe that treating STEM as a culture for pre-service teacher preparation program is one way to ensure that there is ongoing motivation and dedication within the team of STEM educators. This requires social dialogue and constant communication about roles and responsibilities that each member of the team agrees to and is held accountable. A dedicated and highly motivated team is needed despite negotiating personal teaching philosophies, discipline-specific identities and developing personal STEM teacher educator identity.

Recommendation 3. *A consistent mentoring structure for training graduate student STEM instructors*. A significant number of our instructors are graduate students pursuing PhD degrees in science, technology, and mathematics education. Although highly motivated to teach, graduate students often lack the time to devote to coursework and research and may sometimes become challenged by the demands of teaching in a newer Integrated STEM environment. Having a structured mentoring program in place will help graduate students to transition into this teaching role much more smoothly.

Recommendation 4. *Departmental and administrative support including resources and time-release to facilitate the curricular reform*. Any effort toward STEM curricular reform is not a one-event activity (Sunal et al., 2001) but requires a significant time investment from faculty and graduate students who may already be overburdened with responsibilities. Departmental and administrative support that includes resources (such as materials, technology support) and time for facilitating curricular reform is crucial for a sustainable change.

Recommendation 5. *Maintain a critical stance toward students' positioning in STEM.* It is essential that the emphasis on Integrated STEM does not ignore the reality that the practice of STEM is not culturally neutral. As teacher educators, we must attend carefully to the biases that may emerge. Any team attempting STEM integration should maintain a critical perspective that includes identifying and supporting PSTs who may not be equitably positioned in STEM learning and celebrating PSTs' diverse voices and perspectives about STEM. We suggest that STEM teacher educators employ a critical lens as they reflect on their teaching practices and tailor to diverse student needs each semester.

References

Ackermann, E. 2001. Piaget's constructivism, Papert's constructionism: What's the difference. *Future of Learning Group Publication* 5(3): 438.

Atkinson, R., and M. Mayo. 2010. Refueling the US innovation economy: Fresh approaches to science, technology, engineering and mathematics (STEM) education. Information Technology and Innovation Foundation. https://itif.org/files/2010-refueling-innovation-economy.pdf

Bybee, R. 2009. The BSCS 5e: Instructional model and 21st century skills. Presentation. National Academies Press.

Century, J., K. A. Ferris, and H. Zuo. (2020). Finding time for computer science in the elementary school day: A quasi-experimental study of a transdisciplinary problem-based learning approach. *International Journal of STEM Education* 7(20). doi: 10.1186/s40594-020-00218-3

Chen, G. 2011. The rising popularity of STEM: A crossroads in public education or a passing trend? http://www.publicschoolreview.com/articles/408

Chen, Y. L., L. F. Huang, and P. C. Wu. 2021. Pre-service preschool teachers' self-efficacy in and need for STEM education professional development: STEM pedagogical belief as a mediator. *Early Childhood Education Journal* 49(2): 137–147. doi: 10.1007/s10643-020-01055-3

Corp, A., M. Fields, and G. Naizer. 2020. Elementary STEM teacher education: Recent practices to prepare general elementary teachers for STEM. *In* C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, and L. D. English (editors), *Handbook of Research on STEM Education*, p. 101–114. Routledge.

Darling-Hammond, L., and J. Bransford (editors). 2007. *Preparing Teachers for a Changing World: What Teachers Should Learn and Be Able to Do*. Wiley.

DeBari, S., K. Gray, and J. Monet. 2020. Interactions between water, earth's surface, and human activity. *In* A. Egger (editor), *InTeGrate*. https://serc.carleton.edu/integrate/teaching_materials/energy_and_processes/index.html

Delahunty, T., and R. Kimbell. 2021. (Re)framing a philosophical and epistemological framework for teaching and learning in STEM: Emerging pedagogies for complexity. *British Educational Research Journal* 47(3): 742–769. doi: 10.1002/berj.3706

Dewey, J. 1938. *Experience and Education*. Simon and Schuster.

Goo, J. 2019. Fraction street STEM project. https://teachers.makewonder.com/curriculum/fraction-street-stem-project

Harel, I. E., and S. E. Papert. 1991. *Constructionism*. Ablex Publishing.

Heaton, R. M., and W. J. Lewis. 2011. A mathematician-mathematics educator partnership to teach teachers. *Notices of the AMS* 58(3): 394–400.

Huziak-Clark, T., T. Sondergeld, M. van Staaden, C. Knaggs, and A. Bullerjahn. 2015. Assessing the impact of a research-based STEM program on STEM majors' attitudes and beliefs. *School Science and Mathematics* 115(5): 226–236. doi: 10.1111/ssm.12118

Jason Learning. 2019. Water warriors. https://jason.org/portfolio_item/waterwarriors/

Kelley, T. R., and J. G. Knowles. 2016. A conceptual framework for integrated STEM education. *International Journal of STEM Education* 3(1): 1–11. doi: 10.1186/s40594-016-0046-z

Kennedy, T., and M. Odell. 2014. Engaging students in STEM education. *Science Education International* 25(3): 246–258.

Knaggs, C. M., and T. A. Sondergeld. 2015. Science as a learner and as a teacher: Measuring science self-efficacy of elementary pre-service teachers. *School Science and Mathematics* 115(3): 117–128. doi: 10.1111/ssm.12110

Kuhn, T. 1962. *The Nature and Necessity of Scientific Revolutions*. University of Chicago Press.

Madden, L., J. Beyers, and S. O'Brien. 2016. The importance of STEM education in the elementary grades: Learning from pre-service and novice teachers' perspectives. *Electronic Journal for Research in Science and Mathematics Education* 20(5).

Maiorca, C., and M. J. Mohr-Schroeder. 2020. Elementary pre-service teachers' integration of engineering into STEM lesson plans. *School Science and Mathematics* 120(7): 402–412. doi: 10.1111/ssm.12433

Martín-Páez, T., D. Aguilera, F. J. Perales-Palacios, and J. M. Vílchez-González. 2019. What are we talking about when we talk about STEM education? A review of literature. *Science Education* 103(4): 799–822. doi: 10.1002/sce.21522

Menon, D., and T. D. Sadler. 2016. Pre-service elementary teachers' science self-efficacy beliefs and science content knowledge. *Journal of Science Teacher Education* 27(6): 649–673. doi: 10.1007/s10972-016-9479-y

Menon, D., and T. D. Sadler. 2018. Sources of science teaching self-efficacy for pre-service elementary teachers in science content courses. *International Journal of Science and Mathematics Education* 16(5): 835–855. doi: 10.1007/s10763-017-9813-7

Miller, J. 2019. STEM education in the primary years to support mathematical thinking: using coding to identify mathematical structures and patterns. *ZDM* 51: 915–927. doi: 10.1007/s11858-019-01096-y

Moore, T. J., A. C. Johnston, and A. W. Glancy. 2020. STEM integration: A synthesis of conceptual frameworks and definitions. *In* C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, and L. D. English (editors), *Handbook of Research on STEM Education*, p. 101–114. Routledge.

Moore, T. J., and K. A. Smith. 2014. Advancing the state of the art of STEM integration. *Journal of STEM Education* 15(1): 5.

Moore, T. J., M. Stohlmann, H. H. Wang, K. M. Tank, A. W. Glancy, and G. H. Roehrig. 2014. Implementation and integration of engineering in K-12 STEM education. *In* S. Purzer, J. Strobel, and M. E. Cardella (editors), *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices*, p. 35–60. Purdue University Press.

National Academy of Engineering and National Research Council. 2014. *STEM Integration in K-12 Education*: *Status, Prospects, and an Agenda for Research*. National Academies Press. doi: 10.17226/18612

Nesmith, S. M., and S. Cooper. 2020. Elementary STEM learning. *In* C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, and L. D. English (editors). *Handbook of Research on STEM Education*, p. 101–114. Routledge.

NGSS Lead States. 2013. *Next Generation Science Standards*: *For States, by States*. National Academies Press. doi: 10.17226/18290

Papert, S. 1980. *Mindstorms: Children, Computers and Powerful Ideas*. Basic Books.

Paugh, P., and K. Wendell. 2021. Disciplinary literacy in STEM: A functional approach. *Journal of Literacy Research* 53(1): 122–144. doi: 10.1177/1086296X20986905

Pimthong, P., and P. J. Williams. 2021. Methods course for primary level STEM pre-service teachers: Constructing integrated STEM teaching. *EURASIA Journal of Mathematics, Science and Technology Education* 17(8). doi: 10.29333/ejmste/11113

Plumley, C. L. 2019. *2018 NMSSE+*: *Status of Elementary School Science*. Horizon Research.

Rinke, C. R., W. Gladstone-Brown, C. R. Kinlaw, and J. Cappiello. 2016. Characterizing STEM teacher education: Affordances and constraints of explicit STEM preparation for elementary teachers. *School Science and Mathematics* 116(6): 300–309. doi: 10.1111/ssm.12185

Roehrig, G. H., T. J. Moore, H. H. Wang, and M. S. Park. 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. doi: 10.1111/j.1949-8594.2011.00112.x

Ryu, M., N. Mentzer, and N. Knobloch. 2019. Pre-service teachers' experiences of STEM integration: Challenges and implications for integrated STEM teacher preparation. *International Journal of Technology and Design Education* 29(3): 493–512. doi: 10.1007/s10798-018-9440-9

Shaughnessy, M. 2013. By way of introduction: Mathematics in a STEM context. *Mathematics Teaching in the Middle School* 18(6): 324. doi: 10.5951/mathteacmiddscho.18.6.0324

Stohlmann, M., T. J. Moore, and G. H. Roehrig. 2012. Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research* 2(1): 4. doi: 10.5703/1288284314653

Sunal, D. W., J. Hodges, C. S. Sunal, K. W. Whitaker, L. M. Freeman, L. Edwards, R. A. Johnston, and M. Odell. 2001. Teaching science in higher education: Faculty professional development and barriers to change. *School Science and Mathematics* 101: 246–257. doi: 10.1111/j.1949-8594.2001.tb18027.x

Vygotsky, L. S. 1978. *Mind in Society*: *The Development of Higher Psychological Processes*. Harvard University Press.

Wang, H. H., T. J. Moore, G. H. Roehrig, and M. S. Park. 2011. STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research* 1(2): 2. doi: 10.5703/1288284314636

Wang, X. 2013. Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal* 50(5): 1,081–1,121.