Engaging Prospective Elementary Teachers in Integrated STEM Contexts to Learn Mathematics Content and Pedagogy

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While integrated STEM (Science, Technology, Engineering, & Mathematics) has been the focus of several recent policy initiatives, there is no single agreed upon definition of *integrated STEM* (Moore et al., 2020). However, researchers have identified a set of shared practices that connect the STEM disciplines (Moore et al., 2020; Roberts et al., 2022). Some of these practices include *critical and creative thinking to define and solve problems*, *collaborate and use appropriate tools to engage in iterative problem solving*, and *communicate solutions to problems based on evidence and data* (Roberts et al., 2022). Further, researchers have begun to outline methods by which teachers can use integrated STEM to teach mathematics. Throughout this article we refer to integrated STEM to mean the integration of two or more content areas of STEM where students engage in problem-solving related to a real-world environment.

Why focus on integrating the STEM disciplines in instruction? Students' interest in STEM begins in early elementary school (Corp, Fields, & Naizer, 2020). However, students' interest in STEM disciplines has shown to decrease in the upper elementary grades, thus making it increasingly more important for elementary teachers to implement integrated STEM pedagogies in their future classrooms (Shernoff et al., 2017). When teachers use integrated STEM as a context to teach mathematics, students engage in the Standards for Mathematical Practice[i] (SMP) and recognize how mathematics is used in the real world (Roberts et al., 2019). Further, approaching the teaching of mathematics through integrated STEM lessons makes explicit connections to AMTE's *Standards for Preparing Teachers of Mathematics*. Yet, research indicates that most pre-service teachers have little experience with integrated STEM education (Bybee, 2018; Maiorca & Benken, 2019). Teacher preparation programs need to provide opportunities for candidates to engage in integrated STEM experiences.

Below we describe a three-part unit that was designed to introduce elementary pre-service teachers (PSTs) to integrated STEM (Benken & Maiorca, 2021). This unit is embedded in an elementary mathematics methods course that is required at California State University, Long Beach for those seeking an elementary teaching credential. Within this description, we also provide some background information on the learning environment in which the unit is embedded. Throughout, we highlight connections to AMTE's Standards.

The Learning Environment

Learning to teach integrated STEM and mathematics are both grounded in situated learning theory (Maiorca & Mohr-Schroeder, 2020). During class sessions, students are expected to engage in collaborative learning. In the first few weeks, we devote time to intentionally establish a learning environment in which the PSTs are actively co-constructing knowledge with the instructor adopting a facilitator role and engaging in a community of practice (Kelley & Knowles, 2016). Creating a community of practice enables PSTs to become more aware of students' strengths and thinking (*Draw on Students' Mathematical Strengths*, C.4.3*)* and thereby supports them in designing lessons that provide opportunity and access for each and every student (*Provide Access and Advancement*, C.4.1*)*. The interactions of the PSTs within the environment create opportunities to both learn from others and expand/change their perceptions through this learning (Lave & Wenger, 1991). The PSTs participate in an authentic learning environment where they engage in not only integrated STEM practices (including the SMPs) but also integrated STEM pedagogies that they will use in their future classrooms. Per our data from a parallel study, these PSTs have no or little experience with integrating STEM; thus, these experiences with STEM as a learner provide an opportunity for them to envision how such a learning experience may look in elementary classrooms with their own students.

Part 1: Experiencing STEM as a Student

In the first part of the unit, the PSTs experience an integrated STEM unit as a learner through a Model-Eliciting Activity (MEA). MEAs are open-ended, client-driven problems that naturally connect the STEM disciplines through the engineering design process (Maiorca & Stohlmann, 2016). MEAs use the engineering design process to teach mathematics and/or science content in a context that is meaningful to students (Bostic, 2013). The PSTs complete the Survivor Activity (see Appendix A), where they are asked to design a model of a shelter that is sturdy, water-resistant, and spacious enough for people to survive while stranded on an island. The primary mathematical topics include estimation and mathematical reasoning, proportional reasoning, and problem-solving.

For this activity, the concept of proportional reasoning is scaffolded using items in the classroom prior to the PSTs being given the problem statement. In class, the PSTs work collaboratively with a partner to determine a realistic scale and brainstorm materials that they could find in or around their homes. Then, outside of class, the partner teams create their structure and video the process of testing the structure against "nature" (e.g., water, wind). After completing the activity, the PSTs then discuss during class as a whole group which 6^{th} grade Common Core mathematical content standards and SMPs are embedded in the task. In this part of the unit, PSTs engage in the AMTE Standard, *Analyze the Mathematical Content of Curriculum* (C.1.4), because they are asked to identify the mathematical content that is addressed in the Survivor MEA, and they also *Demonstrate Mathematical Practices and Processes* (C.1.2) as they identify the SMPs.

Part 2: Individually Analyzing a Lesson

In the second part of the unit, the PSTs are given a Kindergarten integrated STEM lesson that they analyze outside of class; their task during the next class is to identify Kindergarten mathematics standards, which they believe are addressed in the lesson. After students have been given time to complete this part of the assignment, they engage in small group collaborative discussions focused on justifying where in the lesson their identified content standards are addressed. In essence, they need to reflect on what the central content focus of the lesson is and must provide evidence for their claims. In doing this, the PSTs continue to engage in analysis of the mathematical content as they identify the content standards addressed in the lesson and then the subset of mathematical content that is the focus of the lesson. PSTs also engage in *Demonstrate Mathematical Practices and Processes* and *Understand and Recognize Students' Engagement in Mathematical Practices* (C.3.2*)* when they identify the potential SMPs students might engage during task completion.

Part 3: Creating a Lesson

For the last part of the unit, the PSTs are asked to identify 2-4 3rd grade mathematics content standards that could be used to bridge the Kindergarten and 6th-grade mathematics content discussed during the previous activities; this activity supports *Know Relevant Mathematical Content* (C.1.1). For the culminating activity, the PSTs write an integrated STEM lesson for an elementary grade level of their choosing and thus *Plan for Effective Instruction* (C.2.2). The PSTs are asked to design a lesson that has the characteristics of MEAs (Appendix B). In their lesson plans, the PSTs include advancing and assessing questions that require them to *Anticipate and Attend to Students' Thinking About Mathematics Content* (C.3.1.), as they will need to identify possible student solution strategies. The PSTs are also asked to include the SMPs that they think their students will engage in while completing the task in the integrated STEM lesson (*Understand and Recognize Students' Engagement in Mathematical Practices*).

Conclusion

Using integrated STEM can add meaning and context to learning mathematics. The unit described in this article is one example of how mathematics methods courses can provide needed integrated STEM learning experiences for PSTs that allow them to envision how to help elementary children learn mathematics content while also using the engineering design process and learning science. Through our experiences using this module across multiple semesters, we learned that PSTs have little experience designing integrated STEM lessons that require them to make connections between the STEM content and practices (Kelley & Knowles, 2016); thus, utilizing collaborative experiences in integrated STEM for PSTs is essential. Further, as we adapted the module for the pandemic, we recognized the power of students utilizing their own materials to create the shelter, as it provided a ripe context for the PSTs to engage in authentic modeling. Finally, having students test their shelters on video required them to reflect more carefully on the significance of the design process and fostered connections to the mathematical content.

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Appendix A: Survivor Activity

Problem Statement

Survivor returns to Costa Rica and Mark Burnett, the producer of Survivor, has decided to give survivors the materials to build a shelter as a reward for a challenge. He wants to provide materials to make the shelter as realistic as possible to one that the survivors of a plane crash might build. He will be providing a strip of metal supposedly from a plane, tarp from the rescue raft, rope that has washed ashore, and of course mud from the island. To determine who will be the contestants on the show he wants to see who can design the best scale model of a shelter. The shelter must fit three people and withstand both wind and rain. Design a quality shelter and your team could be on the next show of survivor.

Your shelter must:

- Not move, tip, or be damaged when given three gusts of wind
- Remain dry when given three squirts of water to simulate rain
- Have enough room to fit three people with at least 1 cubic meter of space

Before building your scale model decide on a scale that you will use to determine how much of each material that you will use. For example, if your scale was 1 meter: 2cm, then you would have 20 craft sticks that are 6 cm long.

Actual materials that will be provided on the island	**Materials that you will be given**
Plane siding (2.5 meters x 4 meters)	Aluminum foil: ___ cm x ___ cm
Tarp (1-piece 3 meters x 5 meters)	Wax paper: ___cm x ___ cm
Rope (6 meters)	String: ___ cm

After designing and testing the shelter, record a video for Mark Burnett describing why your shelter is the best. Include in the video the design for the shelter, the materials that you used, the testing of your design, and general guidelines for how to make scale models for any purpose.

Appendix B: MEA Lesson Template

1) Standards
   a. Mathematics Content Standards
      i. Standards for Mathematical Practice
   b. Science Content Standards
      i. Science and Engineering Practices

2) Activity Goals

3) Supplies

4) Building Context Activity

5) Readiness Questions

6) Problem Statement
   a. Questions for students who can't start
   b. Assessing Questions
   c. Advancing Questions

7) Presentation of Solutions
   a. Assessing Questions
   b. Advancing Questions

8) Accommodations, modifications, and differentiation for diverse learners

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[i] California adopted the Common Core State Standards for Mathematics (CCSS-M) in 2010 (https://www.cde.ca.gov/be/st/ss/documents/ccssmathstandardaug2013.pdf).