Integration of STEM Project-Based Learning into Elementary Mathematics Methods Courses: The Case of Properties of Operations

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Introduction

Engaging in and developing algebraic thinking is crucial for students at the elementary level (NCTM, 2009). One aspect of early algebraic thinking that occurs with young children is making sense of operations. For example, the properties of addition are addressed in many first-grade mathematics standards documents, and later in third grade the focus shifts to the properties of multiplication (NGA Center & CCSSO, 2010). Additional algebraic topics considered important for later success in advanced mathematics include exploration of patterns, modeling, and problem solving (Kaput, 2007; Kieran, 2004). Project-Based Learning (PBL) is an instructional approach that encourages real-world connections and performance-based assessments by engaging students in applications of mathematics at early grade levels (Lee & Galindo, 2021).

Developmentally appropriate lessons based on real-life applications enable young learners to visualize algebraic ideas (Benson-O'Connor et al., 2019). However, researchers found that elementary preservice teachers (PSTs) struggled with designing lessons that allow for this type of sense-making with elementary grades students (Ding et al., 2013). There is also recognition that PSTs need additional opportunities to design instruction based on the PBL model (Edwards & Hammer, 2007). A type of lesson that incorporates PBL is the engineering design process, which involves defining problems, developing solutions, and optimizing products. This process has been widely adopted in elementary STEM-focused programs (NGSS, 2013; Lee & Calindo, 2021). With the PBL approach, elementary PSTs can incorporate real-life applications into their mathematics lessons to help students make sense of algebraic topics at a young age.

This article presents PBL lesson plans from PSTs concurrently enrolled in an elementary mathematics methods course and an introduction to STEM education course (STEM Intro). The ideas from the lesson plans demonstrated that PSTs made explicit connections between PBL and important mathematics ideas such as algebraic reasoning. In particular, we describe how two example mathematics lessons developed by PSTs addressed the five essential components of STEM PBL and how these mathematics lessons facilitated elementary students' learning about the properties of operations.

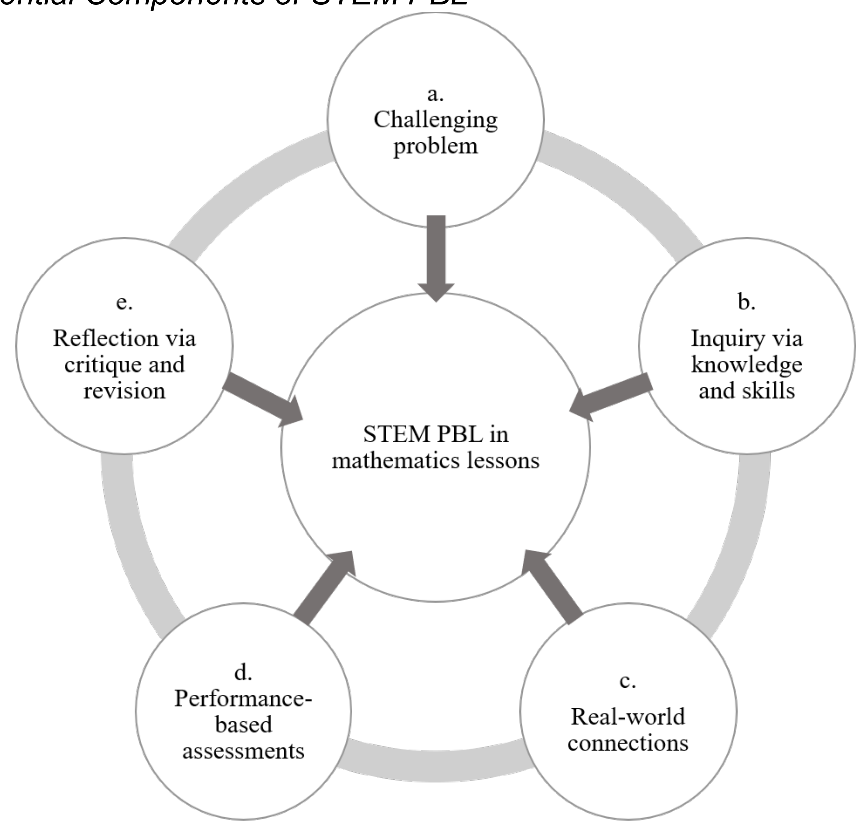
Methods Instruction for PSTs

PBL lessons described in this article were developed as part of an assignment for PSTs enrolled in a mathematics methods course for childhood and elementary education majors (certification grades K–6) at University of Arkansas, Fayetteville. The content covered in the STEM Intro course complemented the mathematics methods course in several important ways. The five components of PBL were introduced in the mathematics method course. However, they were developed in more detail as part of the engineering design process in the STEM Intro course. The lessons described were from PSTs who were also earning a STEM certificate in a course that emphasized the principles of the engineering design process. The dual-enrollment provided these PSTs with the opportunity to learn both mathematics-focused pedagogical methods and STEM applications.

The components of a typical STEM PBL lesson include: (a) challenging problems, (b) inquiry, (c) real-world connections, (d) performance-based assessments, and (e) reflection (see Figure 1). Components (a), (b), and (e) are usually found in several types of mathematics lesson plans. The STEM PBL lesson plan includes all five components in which real-world connections and performance-based assessments are emphasized.

Figure 1

The Five Essential Components of STEM PBL



In this section, the example lesson plans from two PSTs illustrate how they incorporated all five components based on their experiences in both the methods and STEM Intro courses even though they were not required to have all five components for the mathematics assignments. Both lessons exemplified the use of real-world projects as part of the lesson plan.

Snowman Decoration Project

The Snowman Decoration lesson plan was written by a PST who anticipated that her subsequent student teaching semester would be in a first-grade classroom. This lesson was designed to help children analyze and justify how the order of putting winter supplies on their snowmen affected the outcome in terms of quantity. For example, children would work in pairs with a fixed quantity of winter accessories and must record all the possibilities for the order in which they put gloves, hats, scarfs, and socks on their snowmen. The inquiry-based questions the PST listed in the lesson plan were: “What are two different ways to put on the gloves, a hat, a scarf, and socks?”, “What is the total number of items put on your snowman?,” and “Does the order you put them on change the total?” As required by the lesson plan template shown in Appendix A, the PST was required to anticipate how first graders might respond to the problem. The PST identified different orders that students would put items on their snowmen and how they counted or added to get the total. The PST would use the different orders as an opportunity to highlight the commutative and associative properties of addition. This lesson not only reinforced performance-based assessment by having students decorate their snowmen using the provided accessories but also showed that children could apply the relevant properties in real-world settings, such as putting on their own winter accessories.

In the following semester, when the PST taught the Snowman Decoration lesson, she reported that the first graders were fully engaged in using the cutouts to decorate their snowmen. After they finished, she asked them to share the order that they used to put the accessories on their snowmen. As they shared, she wrote the addition sentences that went with their order. She closed the lesson by asking children to conjecture about whether or not they all got the same sum. The first graders were able to use both the equations and their own snowman project to determine that the order of adding the amounts of items did not change the sum.

Parking Lot Project

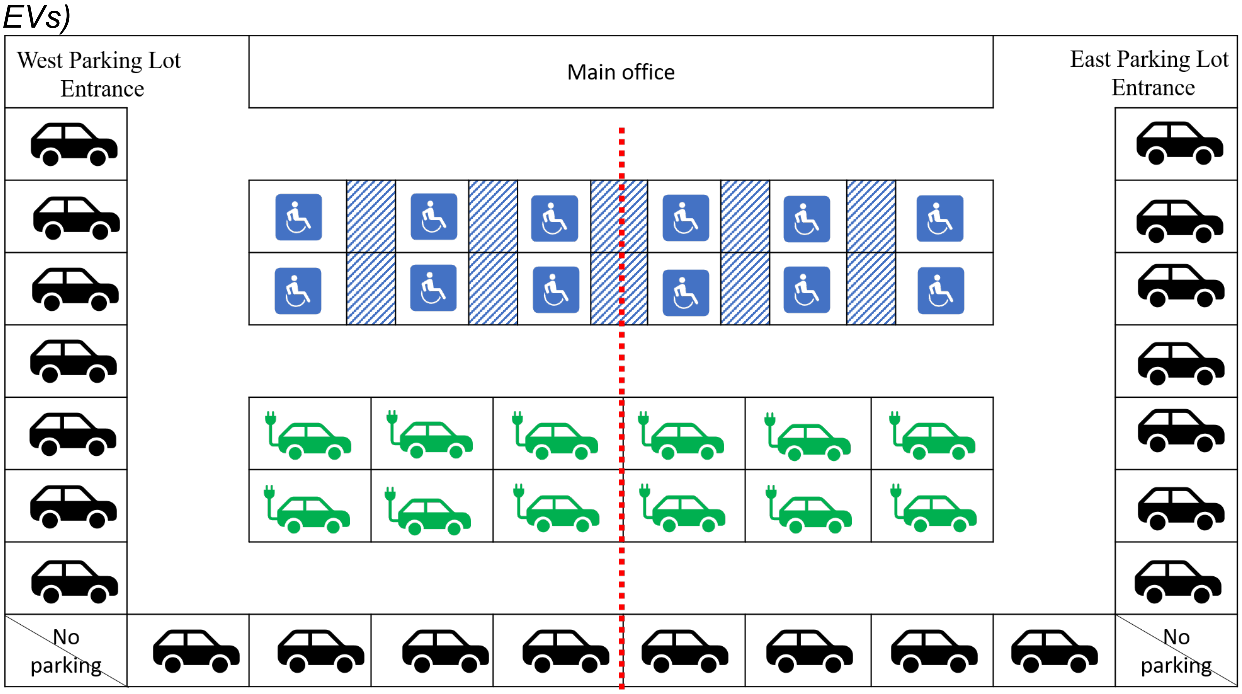
The Parking Lot lesson plan was designed by another PST who anticipated a third-grade student-teaching placement in the semester following the two courses. This lesson plan required children to explore and analyze the arrangement of cars in a 2D parking lot. The materials included an empty parking lot map with several cutouts for regular cars, electric vehicles (EVs), and disability parking images. After students applied the engineering design process to complete the school parking lot model, they would have to justify the number of cars parked on the lot through drawings, numbers, and equations. The underlying mathematics content was the distributive property of multiplication over addition. In particular, this project required students to: (a) manipulate the arrangement of parking spaces to outline the structure of multiplication, (b) represent the visitor spaces in distinct equations with accurate computations, (c) see mathematics as a useful tool to solve parking problems in a real-life situation, (d) apply logical justification when representing the total number of parking spaces, and (e) demonstrate strategic competence through formulating equations for different quantities of parking spaces.

This lesson was designed to assess children's mathematical proficiencies by examining their thinking process as they thought about ways to determine the total number of regular parking spots and EV spots. The PST wanted her third graders to have the opportunity to present their formulas, equations, justifications, and visual representations. The PST anticipated that the third-grade students would determine the total number of visitor parking spaces as x regular spots plus y EV parking spaces in both the east and west parking lots with the equation $2 \times (x + y)$. The PST also anticipated that some of the students might relate it with another equation, $2 \times x + 2 \times y$.

The PST taught the parking lot lesson to a third-grade class in the next semester. An example parking lot diagram created by a third grader following the engineering design process is shown in Figure 2. In her reflections following the implementation of the lesson, the PST shared that students came up with both equations that illustrated the distributive property. She also had an opportunity to help the third-graders who only used addition to represent the number of parking spaces make connections to multiplication and equal groups situations. For example, she used equations and True/False questions to help students who used repeated addition make the connection between $11 + 11$ and 2×11.

Figure 2

School Parking Lot Model (Black Spaces for Regular Parking and Green Spaces for EVs)



Conclusions

The two foredescribed lessons were developed in a mathematics methods course and carried out during the following semester in these PSTs' student-teaching placements. Our PSTs asserted that planning mathematics lessons with real-world connections took time and effort. However, they expressed appreciation for the STEM Intro course, which provided the opportunity to incorporate the PBL approach into mathematics lesson plans. During the implementation of these lessons, our PSTs were particularly pleased with the use of performance-based assessments via the two hands-on projects that show the real-world connections in mathematics classrooms. These example lessons from PSTs illustrated the benefit of a variety of interdisciplinary courses, including mathematics methods, science methods, and STEM-focused courses, in their teacher education programs. Mathematics teacher educators can help PSTs develop effective mathematics pedagogy in methods courses through integrating knowledge and skills learned in relevant STEM disciplines, such as PBL and the engineering design process.

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Appendix A: Mathematics Lesson Plan Template

Title of Lesson:
Grade Level:
Key Knowledge:

- Mathematics Content standards (CCSSM http://www.corestandards.org/Math/):

***Learning goals:**

- **Understand** *(Big ideas, principles, generalizations, rules, etc.*):
- **Know** *(Facts, vocabulary, definitions, etc.*):
- **Do** (*Thinking skills, skills of the discipline, etc.*):

Prior Knowledge: *(State what the students have already learned before or in the preceding grade to be successful in this activity)*
Materials, Resources, and Supplies: *(Manipulatives or resources needed for this activity)*
Procedure for Teaching the Lesson: *(provide a detailed step-by-step outline)*

- Entry event (e.g., how to hook the students):
- Rules of this activity (e.g., how to conduct this activity):
- How to engage students (e.g., I do, we do, you do; any competition; what is the reward?):
- How to assess students' learning (e.g., How to know the students have learned the concept):

Anticipated Outcome:
Differentiation/Extension: *(how to differentiate content, process, products, or the learning environment)*
Standards for Practice:

- SMP (http://www.corestandards.org/Math/Practice/):

Reflection:

a. What is this mathematical lesson about?
b. What inspired your team to design this mathematical lesson?
c. How do you know this mathematical lesson is appropriate for students on this grade level?
d. How can this activity facilitate students' ability to solve a real-world problem?
e. What are the pros and cons of using this mathematical lesson in the classroom?
f. In your lesson, what is the most important condition you took into consideration?
g. How does this mathematical lesson align with the learning outcomes (e.g., be specific on what students will understand, know, and can do)?
h. What strategy do you anticipate your students to use in this lesson? Give some examples.
i. What difficulties or misconceptions might your students have?

*PST example lessons presented in this article also included components (c) and (d) from the STEM PBL essential components diagram as a result of their concurrent enrollment in the methods course and STEM Intro course.