Case Studies: Pre-Service Mathematics Teachers' Integration of Technology into Instructional Activities Using a Cognitive Demand Perspective

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Abstract: This study aims to investigate pre-service teachers' integration of technology and how the integration of technology influences the level of cognitive demands of the mathematics tasks in their mathematics technology activities. The purpose of this study was to investigate the various levels of cognitive demands of mathematical tasks created or modified by pre-service mathematics teachers for technology activities. This study presents case studies of pre-service teachers chosen from a group of participants, and these PSTs come from a variety of backgrounds. Showcase Portfolios and lesson plans were gathered in order to comprehend the selection/creation of mathematical tasks and how they were intended to be implemented in the classroom by PSTs. This study offers suggestions for teacher preparation to integrate technology into mathematics instruction in ways that support students' learning through a review of results, the cognitive demands of mathematical tasks in PSTs' technology activities.

Keywords: cognitive demands of the mathematics tasks, case studies, technology integration, pre-service mathematics teachers

INTRODUCTION

We live in a technological and mathematically advanced era. New technologies are developed on the basis of mathematical knowledge (Kilpatrick, Swafford, Findell, & National Research Council, 2001); thus, people must be able to understand and do mathematics in order to effectively participate in opportunities to shape the future (National Council of Teachers of Mathematics [NCTM], 2000, 2014). Today's students cannot survive economically in the twenty-first century without technology-supported learning opportunities, and traditional education cannot provide these opportunities for students (International Society for Technology in Education, [ISTE], 2000). One of the six central principles for school mathematics addressed in the NCTM Principles to Actions: Ensuring Mathematical Success for All (2014) is technology. According to the NCTM technology principle, "technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (p. 24).

Over the last 40 years, teaching strategies and school curricula have evolved significantly (Heddens & Speer, 2006). Today's students are frequently bored during direct instruction lessons in mathematics and other subjects because they only need to listen to the lecture and sit in their chair (Schrum & Levin, 2009). Because today's students have grown up in a technological era, our educational system should take this into account when developing curriculum and instructional strategies. "Incorporate and support the effective use of appropriate tools and technology in mathematics curriculum standards across all grade levels" (NCTM, 2014, pp. 111-112). Incorporating technology into the educational process provides students with an interactive learning experience that allows them to remain engaged in the subject matter (Haleem et al., 2022). Furthermore, using technology to teach mathematics increases students' involvement in the learning process (Getenet, 2020).

Students in the twenty-first century differ from previous generations. Students must be taught differently because they learn and think differently than adults (e.g., teachers and school leaders), who are referred to as digital immigrants (Prensky, 2001; Schrum & Levin, 2009). The primary distinctions between digital natives and digital immigrants are their levels of comfort with technology, as well as their approaches to information processing and learning through technology (Cunningham, 2012; Zur & Zur, 2011). Technology is simple to use and understand for digital natives (Schrum & Levin, 2009). When compared to digital immigrants, digital natives use technology to access information quickly and effectively communicate with their peers (Cunningham, 2012). The term "digital natives" refers to two fundamental expectations. To begin, educational methods should be tailored to promote rapid, relevant, and pragmatic learning. Second, there is a need for educators to develop a common technological vernacular that speaks directly to this demographic (Zuluaga Trujillo & Gómez Montero, 2019).

Technology has the potential to improve the quality of mathematical investigations, present meaningful mathematical ideas to students and teachers from various perspectives, and change traditional ways of doing mathematics (NCTM, 2000). The use of technology in the classroom may increase children's involvement in the learning process (Hallem et al., 2022). According to The NCTM Principles to Actions: Ensuring Mathematical Success for All (2014), technology not only improves students' understanding and learning of mathematics, but it also assists teachers in making instruction more effective and meaningful for students. Effective mathematics instruction is required for all students in all classrooms to improve their mathematical understanding. Teachers use various teaching styles and strategies to teach specific mathematical concepts, and there is no one way to teach. Teachers' mathematical knowledge and understanding are important factors in influencing decisions and actions in their mathematics classrooms to improve students' learning (Anthony & Walshaw, 2009; Ball, Thames, & Phelps, 2008).

One of mathematics teachers' responsibilities is to provide various opportunities for their students to develop mathematical thinking. Teachers require resources to expand their knowledge and refresh their strategies for effective mathematics teaching and learning (NCTM, 2000). Teachers plan the mathematical tasks that will be used in mathematics lessons and design how these tasks will be implemented in class to improve students' thinking. A mathematical task is defined as "a classroom activity designed to direct students' attention toward a specific mathematical concept, idea, or skill" (Henningsen & Stein, 1997, p. 528). Tasks are identifiable and meaningful elements that are used to evaluate and create curriculum, teaching methods, and assessment strategies (Tekkumru-Kisa & Stein, 2015). According to research, mathematics tasks are critical for students' learning and for improving their reasoning skills (Boaler & Staples, 2008; Stein & Lane, 1996). Other essential roles of teachers include focusing on the relationship between tasks and student thinking, selecting high-level tasks (e.g., tasks that promote higher order thinking) for mathematics instruction, and implementing these tasks in ways that maintain high-level cognitive demands (Boston & Smith, 2009; Stein, Grover, & Henningsen, 1996). The use of various, meaningful, and valuable mathematical tasks is associated with effective teaching and improving students' mathematical skills (Glasnovis Gracin, 2018).

The selection of mathematical tasks has significant implications for students' understanding of mathematics as well as the quality of their mathematical thinking and learning. As a result, it is critical to comprehend the role that technology may play in the tasks that teachers choose to assign to their students. Mathematics teachers are increasingly likely to use technology-enhanced teaching methods and integrate technology into their classroom practices (Joubert et al., 2020). Mathematics teachers' roles in the classroom are critical for the effective use of technology in ways that support students' mathematical understanding (NCTM, 2000, 2014). Mathematics teachers are not replaced by technology, but rather make decisions about how and when to use technology as a supplement in the teaching and learning environment (NCTM, 2000, 2014). Sherman (2014) emphasized the significance of using technology to assist students in improving their high-level mathematical thinking. Using technology to support student learning entails using technological tools to provide and sustain student engagement in high-level tasks and thinking.

Attending to the cognitive demand of technology tasks used in mathematics teaching and learning serves as a productive focus for effectively using technology; however, research shows the complexity of teaching mathematics using cognitively challenging tasks (Boston & Smith, 2009; Henningsen & Stein, 1996). Sherman (2014) observes that teachers struggle to maintain high-level demands during implementation (i.e., throughout a lesson) when using technology, despite having selected and set up high-level tasks at the start of the lesson. Professional development can help teachers carry out high-level tasks (Boston & Smith, 2009, 2011). As a result, teachers require training to influence the use of technology in education, which should begin in teacher preparation programs.

Teacher Preparation

Training in how to use technology effectively to support students' mathematical learning should begin in teacher preparation programs. In teacher preparation programs, future educators are prepared to gain pedagogical and subject matter knowledge as well as early teaching practice (Feuer, Floden, Chudowsky, & Ahn, 2013). Furthermore, teacher preparation programs should provide prospective teachers with the tools they will need in the classroom, such as educational technology (Edutopia, 2008). In her article, Niess (2008) states that "with the addition of an integration of new and emerging twenty-first century technologies as tools for learning, the preparation of teachers must evolve toward preparing preservice teachers to teach in ways that help them to guide their students in learning with appropriate technologies" (p.224).

Hence, it is critical that training in the effective use of technology in pedagogy (processes, practices, and methods of teaching and learning) and content (mathematics subjects such as number and quantity, algebra, functions, geometry, statistics, probability, and calculus) begin in mathematics teacher preparation programs. ISTE (2000) created technology standards to help pre-service teachers integrate technology into their classrooms. Teaching with technological tools should be emphasized in teacher preparation programs (Mishra & Koehler, 2006), as many pre-service teachers, and even in-service teachers, are unaware of the technologies availability for use in the classroom (Lin, 2008). The significance of teacher preparation programs cannot be overstated, because such programs can provide positive experiences with technology for PSTs in mathematics teaching and learning (Browing & Klespis, 2000). According to Garofalo et al. (2000), "PSTs need to develop technology skills, enhance and extend their knowledge of mathematics with technological tools, and become critical developers and users of technology-enabled pedagogy" (p. 86).

After graduating, pre-service teachers (elementary, middle, and secondary level) are expected to teach mathematics lessons and, ideally, integrate technology into their instruction, but many of them have not had enough opportunities during coursework to learn how to integrate technology effectively into their lesson activities. There are numerous technology tools available for pre-service teachers, as Johnston (2009) stated that "little is known about how pre-service elementary teachers evaluate technology tools as they plan for instruction" (p.1). According to the literature, PSTs require opportunities during their preparation program to plan and implement technology-enhanced lessons. Understanding how PSTs can be supported to plan lessons that integrate technology to effectively support students' mathematics learning will make a significant contribution to the field's knowledgebase.

In conclusion, technology is critical in education, particularly in the teaching and learning of mathematics. There are numerous technological tools available to teachers, and teachers must choose and implement technology in ways that support students' mathematical learning. Teachers require training to effectively use and integrate technology in their lesson activities, and this training should begin in teacher preparation programs.

Significance of Study

When considering the role of technology in addressing student learning, there are two important and distinct approaches to consider: (a) the quality of instruction and (b) the impact on student learning. These two approaches are linked to and influence student learning in education, particularly mathematics education. Many studies investigated how technology has affected students' learning and understanding of mathematics (such as Shin, Sutherland, Norris, & Soloway, 2012), and a few key studies have looked at how using instructional technology affects teachers' task implementation and students' complex thinking in the classroom (e.g., Sherman, 2014). According to Hollebrands, Conner, and Smith (2010), the majority of studies have focused on the use of technology and how it affected the learning of the NCTM Content Standards (number and quantity, algebra, functions, geometry, statistics, probability, and calculus), but fewer studies have focused on how technology supports learning of the NCTM Process Standards (problem solving, reasoning and proof, communication, connection, and representations).

According to Rice, Johnson, Ezell, and Pierczynski-Ward (2008), addressing learners' needs, using best teaching strategies, and teaching the standards are insufficient without the integration of technology for the process of effective planning. Few studies have been conducted on how PSTs use and integrate instructional technology for instruction. The following research questions will be addressed in this study:

- What is the level of the cognitive demands of mathematical tasks created or modified by pre-service mathematics teachers for technology activities?
- How does the integration of technology change the level of cognitive demands of mathematics tasks in mathematics technology activities?

METHOD

The purpose of this study was to investigate the various levels of cognitive demands of mathematical tasks created or modified by pre-service mathematics teachers for technology activities. This study presents case studies of pre-service teachers chosen from a group of participants, and these PSTs come from a variety of backgrounds. This section's comments and descriptions are based on lesson activities and/or samples of student work (for Showcase Portfolios only). Showcase Portfolios and lesson plans were gathered in order to comprehend the selection/creation of mathematical tasks and how they were intended to be implemented in the classroom by PSTs.

Participants

This study chose five PSTs with diverse academic backgrounds, including two elementary level PSTs (Zack and Emily), two secondary level PSTs (Dora and Carrie), and a group of middle level PSTs (three PSTs collaborated to create this activity). A pseudonym was used to identify all data collected from participants, and the pseudonym is used throughout this paper (Table 1).

Participant (Pseudonym)	Grade Level	Technology	Task sources
Zack	Elementary Level	Smartboard	NCTM/Illumination
Emily	Elementary Level	iPad or a computer	NCTM/Illumination
Dora	Secondary Level	Smartboard	NCTM/Illuminations
Carrie	Secondary Level	Graphic Calculator	Created herself
Group of PSTs	Middle Level	Smartboard	Exchange Smarttech website

Table 1: Participant Information

Research Design

The researcher presented case studies to further investigate the understanding of how pre-service mathematics teachers selected mathematical tasks and aimed to implement them in the classroom environment. Case studies, according to Yin (2003), are "an empirical inquiry that investigates a contemporary phenomenon within its real-life context" (p.13-14). The case studies can be single or multiple case studies, and in this study, a multiple case study approach was chosen because the grade level of technology activities created by PSTs differed in each case.

Data Collection

This data source was examined to determine whether the level of cognitive demands was maintained, decreased, or increased during implementation, as well as student response. This study examined the types of mathematical tasks chosen by PSTs, how PSTs implemented these tasks, how students were expected to answer these tasks, and their relationships. The technology activities from the mathematics pedagogy course and the student teaching showcase portfolio (e.g., copies of technology activities used while student teaching and samples of student work from those activities) were collected for this purpose.

Data Analysis

The Instructional Quality Assessment (IQA) Mathematics rubrics were used to analyze technology activities (Boston, 2012). The IQA Mathematics Rubrics were used to determine the cognitive demand of the instructional task as well as the level of cognitive process engaged in by students while working on the task. "The IQA Toolkit was created to provide statistical and descriptive data about the nature of instruction and students' learning opportunities" (Boston, 2012, p. 5). The Levels of Cognitive Demand and the Mathematical Tasks Framework were used to create IQA rubrics.

	Task Type	
Low Level Cognitive Demands	Memorization	Involve either reproducing previously learned facts, rules, formulas, or definitions or committing facts, rules, formulas or definitions to memory. Cannot be solved using procedures because a procedure does not exist or because the time frame in which the task is being completed is too short to use a procedure. Are not ambiguous. Such tasks involve the exact reproduction of previously seen material, and what is to be reproduced is clearly and directly stated.

		Have no connection to the concepts or meaning that underlie the facts, rules, formulas, or definitions being learned or reproduced.
	Procedures without connections	Are algorithmic. Use of the procedure either is specifically called for or is evident from prior instruction, experience, or placement of the task. Require limited cognitive demand for successful completion. Little ambiguity exists about what needs to be done and how to do it. Have no connection to the concepts or meaning that underlie the procedure being used. Are focused on producing correct answers instead of on developing mathematical understanding. Require no explanations or explanations that focus solely on describing the procedure that was used.
High Level Cognitive Demands	Procedures with connections	Focus students' attention on the use of procedures for the purpose of developing deeper levels of understanding of mathematical concepts and ideas. Suggest explicitly or implicitly pathways to follow that are broad general procedures that have close connections to underlying conceptual ideas as opposed to narrow algorithms that are opaque with respect to underlying concepts. Usually are represented in multiple ways, such as visual diagrams, manipulatives, symbols, and problem situations. Making connections among multiple representations helps develop meaning. Require some degree of cognitive effort. Although general procedures may be followed, they cannot be followed mindlessly. Students need to engage with conceptual ideas that underlie the procedures to complete the task successfully and that develop understanding.
	Doing Mathematics	Require complex and nonalgorithmic thinking—a predictable, well-rehearsed approach or pathway is not explicitly suggested by the task, task instructions, or a worked-out example. Require students to explore and understand the nature of mathematical concepts, processes, or relationships. Demand self-monitoring or self-regulation of one's own cognitive processes.

	Require students to access relevant knowledge and experiences and make appropriate use of them in working through the task. Require students to analyze the task and actively examine task constraints that may limit possible solution strategies and solutions. Require considerable cognitive effort and may involve some level of anxiety for the student because of the unpredictable nature of the solution process required.

Table 2: Four Types of Mathematical Tasks (Stein, Smith, Henningsen, & Silver, 2009)

The IQA Mathematics rubrics were used to assess the instructional quality of technology-based instructional activities using three indicators: the written instructional task, task implementation, and expected student responses. Data from PST technology activities will be graded using the Instructional Quality Assessment (IQA) Academic Rigor (AR) in Mathematics rubrics for Task Potential, Described Implementation, and Expected Student Responses.

Potential of the Task. The cognitive demand of the mathematical task as it appears (i.e., as written or on screen) in the technology activity is coded as The Potential of the Task. The original IQA Academic Rigor 1 (AR1) rubric will be used to code each task. The researcher coded Potential of the Task as "did the task have potential to engage students in rigorous thinking about challenging content?"

Described Implementation/Implementation. Task implementation is described as the level at which the teacher supports students to engage with the task throughout the lesson, or how tasks are enacted during instruction. For data from PSTs' student teaching (e.g., instructional activities and student work), the cognitive process evidence in students' written work will be scored for Task Implementation using the IQA Mathematics Assignments-Academic Rigor rubric for Implementation (AR2). For data from the methods courses, PSTs' technology activities will be coded for "Described Implementation" based on the description of how the PST aims to use the technology tasks in the instructional activity. The rubric for Described Implementation was modified from the original IQA Mathematics Academic Rigor-Implementation rubric (AR2) and was tested during the pilot study and another study of cyber-based curriculum.

Expected Student Responses/Student Responses. Expected student response is the extent to which students show their work and explain their thinking about the important mathematical content. The Expected Student Response rubric was modified from the original Academic Rigor 3 (AR3) Elaborates of Student Responses rubrics in the IQA Mathematics Assignments rubrics and tested in the pilot study. The modified rubric will be used to score "expected students' responses" in PSTs' technology activities from the methods courses. The original "Elaborates of Student Responses" rubric will be used to score samples of students' work from PSTs' student teaching lesson activities.

CASES

The cases presented in this section demonstrate: 1) how PSTs used the same task in different ways; 2) how PSTs maintained high level cognitive demands during implementation and student responses; 3) how PSTs reduced high-level cognitive demands during implementation and student responses; and 4) how PSTs increased high-level cognitive demands during implementation and student responses. These cases were chosen because they demonstrated how PSTs attempted to implement various tasks in various ways.

Integration of same task differently

The first case illustrates how the same technology task is described and used differently in different lesson activities. This task is retrieved from http://illuminations.nctm.org/Activity.aspx?id=3540 and is illustrated in Figure 1.

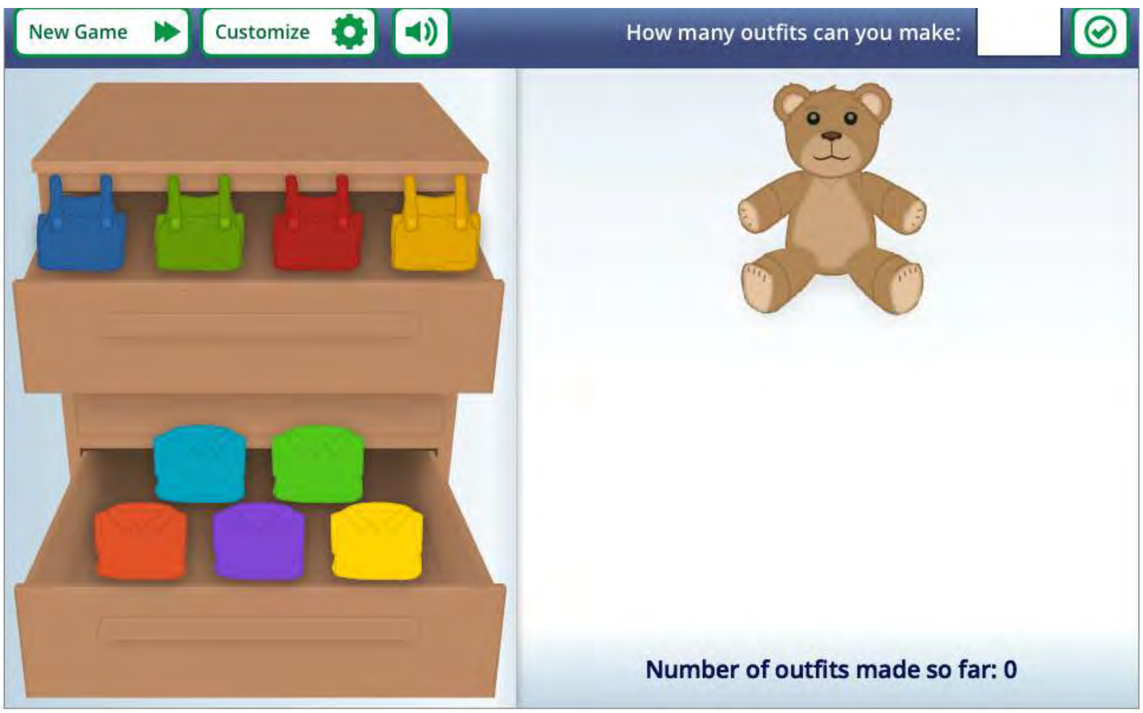


Figure 1: Screenshot of Bobbie Bear activity

This "Bobbie Bear" activity can be used in a Pre-K to Fifth Grade classroom to help students learn about using counting strategies to see how many different outfit combinations they can make for Bobbie Bear. By putting together different outfit combinations, students can learn about combinations, addition, and multiplication. The customized settings differ by grade; the only thing that changes is the number of shirts and pants. The teacher can specify how many different pairs can be created and which levels of difficulty the students use. The activity's instructions are as follows: "Bobbie Bear is planning a vacation and wants to know how many outfits can be made using different colored shirts and pants." "How many outfits can you put together?"

This activity also includes five questions for the teacher to use as a source of exploration with the students in order to broaden their knowledge (however, there is no lesson plan, suggested activity, or handouts that correspond with the applet).

- How many outfits do you think can be made?
- How do you know when you have made all the outfits?
- If you are missing an outfit, how do you find out which one it is?
- How can you organize your work to make answering these questions easier?
- Try your strategy for more shirts and pants using the Customize button.

The Task's Potential receives a 3 because students are asked questions that allow them to identify the combination of different colored shirts and pants. The task has the potential to engage students in the process of making sense of mathematical concepts and procedures. Because the task does not necessitate an explanation or evidence of students' reasoning and understanding (e.g., generalizing a shortcut or explaining why repeated addition, multiplication, a tree diagram, or the Fundamental Counting Principle is an appropriate strategy), it does not receive a 4, and thus does not receive a 4.

The Described Implementation and Expected Student Response scores can differ depending on how PSTs describe the task or technology's implementation within the instructional activity. The researcher provides examples from two cases below of how PSTs implement the same task in different ways and expect different student responses.

Zach is the first PST, and he was enrolled in the PK-4 Numeracy Pedagogy course (e.g., elementary mathematics methods). Zach used the SmartBoard to demonstrate the "Bobbie Bear" activity by incorporating the National Council of Teachers of Mathematics (NCTM) Illumination website. The reason for choosing this website was to address important mathematical content, as the activity he chose includes a variety of activities with addition. Zach emphasized the importance of teaching children addition concepts at a young age because "it is the foundation of a lot of different mathematical concepts they will encounter later in life."

Students learn about combinations and what they mean by adding up the various outfit combinations in this activity. Zach described task implementation as the teacher beginning the lesson by explaining different combinations and providing examples of different combinations. The implementation is then explained by Zach as follows:

> When the class has a solid foundation, the teacher can poll the students to see how many different outfits they can make for Bobbie Bear. After recording the class estimate, the teacher can direct students to come up to the board and drag the two pieces of clothing onto the bear. The teacher will then repeat this process until the class agrees that no more combinations are possible. The teacher will then be able to compare the class's estimate to

the number of outfits they were able to produce. The teacher can then check the students' answers, and the program will tell the class whether or not they were correct.

He described the procedure-level implementation, and his Described Implementation score is a 2. Students must focus on correctly executing a procedure to obtain a correct answer, rather than exploring, building meaning, explaining, or supporting their ideas. In fact, the described implementation makes no references to addition. Student Response receives a score of one because students are only asked to provide a brief numerical answer and find the correct number of combinations by typing numbers into the box. Zach reduced the cognitive demands for Described Implementation and Expected Student Response from high to low.

Emily is the second PST, and she is enrolled in the PK-4 Numeracy Pedagogy course. In her activity, the children could do the "Bobbie Bear" activity together on an iPad or a computer. She chose this project due to the fact that "this would be a fun interactive way for the students to apply their probability and computing possibilities knowledge in a fun and exciting way using technology" . During the implementation, she wanted the students to share their various problem-solving strategies. Furthermore, she stated that this activity could be used as an informal assessment of the children's knowledge: "While the students were playing this game, I could formatively assess them by walking around the room and seeing different strategies the students are using within their problem solving."

Emily described implementation at the "procedures with connections" level, and the Described Implementation score is 3, because students create meaning for mathematical procedures and concepts but are not explicitly required to produce explanations (e.g., to explain why 3 shirts and 4 pants result in 4 x 3 or 12 outfits), so it does not score a 4. Expected Student Response receives a 3 as well, because students must provide evidence of mathematical thinking and reasoning, such as multiple strategies, but no explanation is required. Emily keeps the cognitive demands for Described Implementation and Expected Student Response at the same level.

Lesson plans are part of the intended curricula, as described in Chapter 2, and the teacher's thinking about how lessons should be taught can be reflected in lesson plans (Remillard, 1999; Stein, Remillard, & Smith, 2007). Both PSTs chose the same task using the same technology activity (intended curriculum), but they aimed to enact the activity in different ways (enacted curriculum).

Maintenance of High-Level Cognitive Demands

This case demonstrates how PSTs maintained the cognitive demands of mathematical tasks while implementing them and anticipating student responses. Dora, the PST, was enrolled in Teaching Secondary Mathematics (e.g., secondary mathematics methods course). In a high school level (Grades 9-12) Algebra class, she creates an activity that involves the use of virtual Algebra tiles. Dora chose Algebra tiles, which are mathematical manipulatives designed to help students visualize symbolic representations through concrete models. Algebra tiles provide students with an alternative method of solving algebraic problems other than abstract manipulation. Algebra tiles can be used to practice a wide range of mathematical concepts, such as adding and subtracting integers, multiplying polynomials, factoring, and completing the square.

The task is to solve linear equations using Algebra tiles, and she chose an applet from the NCTM illuminations website (http://illuminations.nctm.org/activity.aspx?id=3482), as shown in Figure 2. Dora believes that this Internet applet is beneficial to students because it allows them to use technology to solve a mathematical concept rather than pencil and paper, and it allows students to visually see what they are doing to solve an equation.

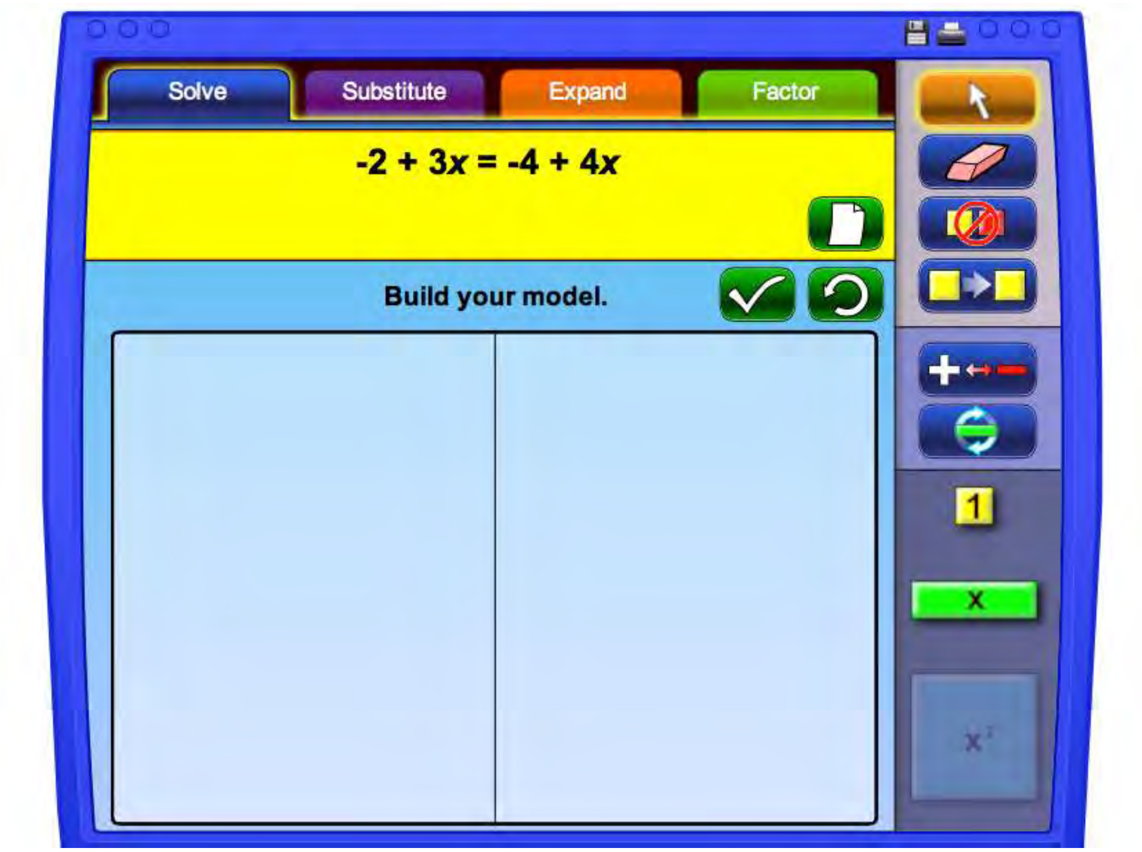
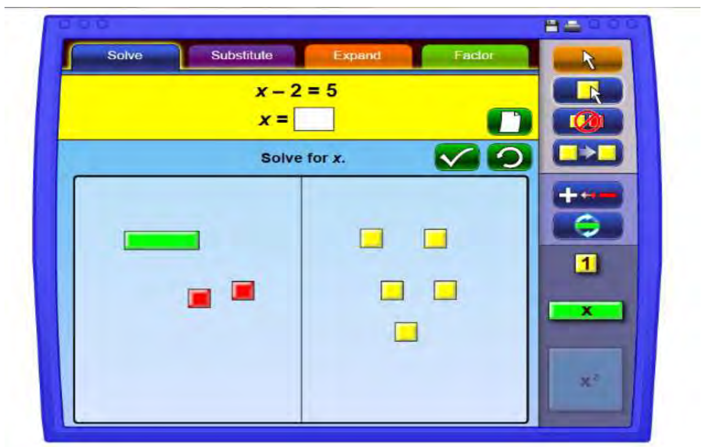


Figure 2: Screenshot of NCTM illuminations website

The task requires you to build a model and solve an equation. The website also includes a list of activities that students can do with applets: "Learn how to represent and solve algebra problems by using tiles to represent variables and constants." Solve equations, use variable expressions as substitutes, and expand and factor. "Flip tiles, remove zero pairs, copy and arrange your way to a better understanding of algebra." Because students are asked to build their own model, the Task's Potential is a 3. The task has the potential to engage students in the process of making sense of mathematical concepts and procedures. Dora outlined the process in detail:

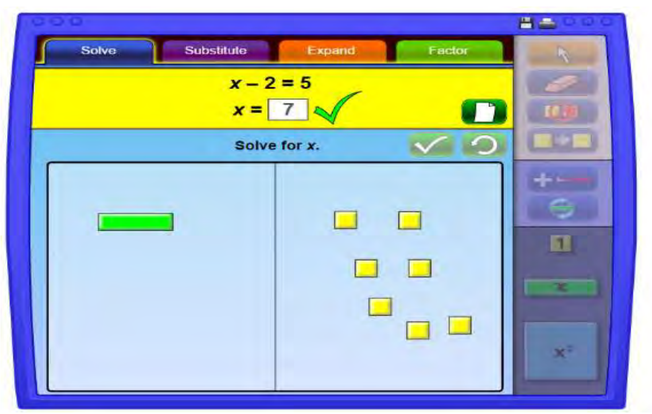
1. Start with an equation

2. Use the pointer tool and place the correct pieces in the workspace. After you build the model of the given problem, check your answer to move on to the next step. Only tile type, tile quantity, and workspace area are checked, not the way in which tiles are arranged.



3. Try eliminating the necessary tiles to create zero pairs. Remember, what you do to one side, you must do to the other side!

4. After you solve the problem, check your answer.



5. Practice: Solve the following equations using the Algebra tiles:

a) $4x - 1 = 2x + 3$

b) $2x + 2 = 4$

c) $4x - 3 = 5$

d) $5x - 5 = 4x + 2$

Figure 3: Screenshot of Dora lesson plan

Dora planned to ask three questions after the students practiced above problems. These questions are:

1) How do the Algebra tiles allow you to better visualize the concept of zero pairs?

2) Explain the phrase “whatever you do to one side, you must do the exact same thing to the other side”?

Dora described procedures with connection level implementation as requiring complex thinking. The Described Implementation score is 4 because students must explain and comprehend the nature of mathematical concepts and procedures. Expected Student Response also receives a 4 because students must provide evidence of mathematical thinking and reasoning, such as multiple strategies, as well as explanation. Dora's described implementation maintained the high level cognitive demands of the original task and increased the score level from 3 to 4 for Described Implementation and Expected Student Response.

This case illustrates the preservation of high-level task demands for described implementation and anticipated student response. This case is significant because task implementation resulted in higher student achievement by maintaining the cognitive demand of instructional tasks. Figure 4 depicts the patterns of set up, implementation, and student learning described by Stein and Lane (1996). High-level cognitive demands during task setup and maintenance lead to high-level student learning.

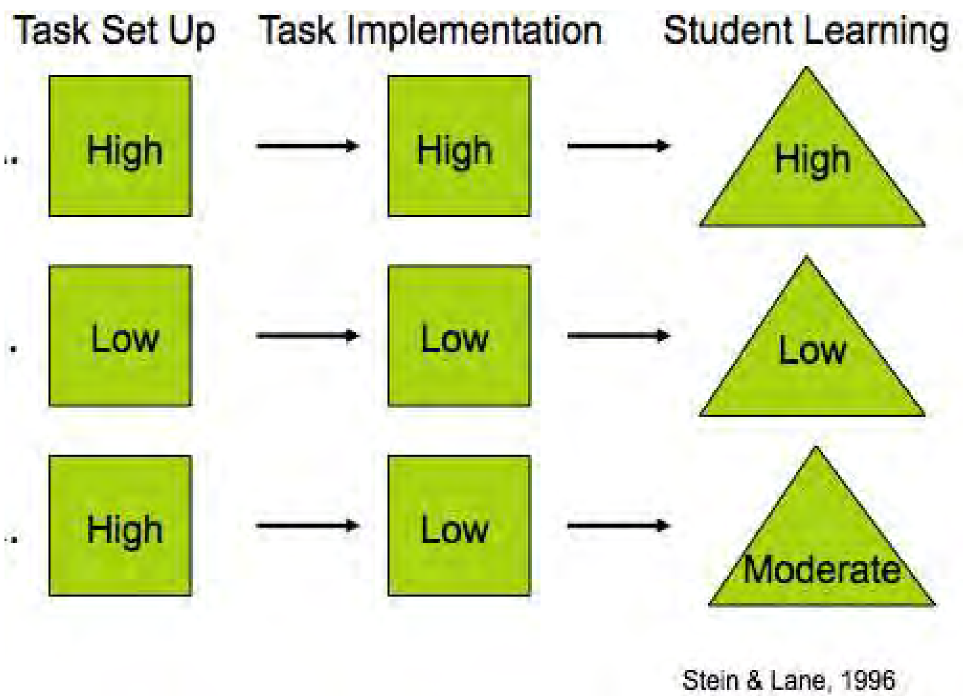


Figure 4: Patterns of Set up, Implementation, and Student Learning

Increasing Low-Level Cognitive Demands

In this case, it is discussed how PSTs increased the cognitive demands of mathematical tasks during implementation and the expected student response. PSTs (working in groups of three) from the Teaching Middle Level Mathematics (middle level mathematics methods) course created this activity. This activity demonstrates how PSTs increased low-level mathematics tasks with high-level cognitive demands during Described Implementation and Expected Student Response. It is a SmartBoard activity called "Perimeter Patch" that deals with the concepts of area and perimeter. Figure 5 shows the activity that was chosen from http://exchange.smarttech.com/details.html?id=a06612eb-f7ec-43b4-9ae8-3e5b9784a7f1.

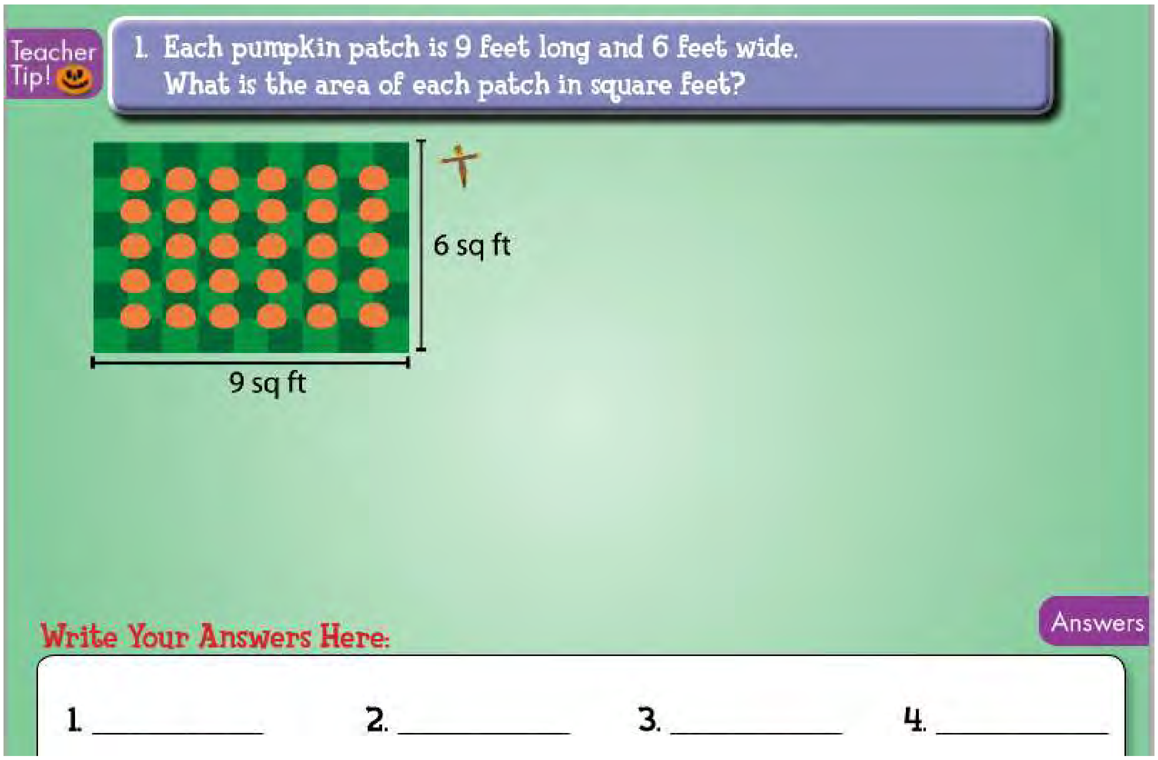


Figure 5: Screenshot of Middle Level PSTs' Lesson Activity

SmartBoard was chosen as a technological tool by this group because "it allows students to complete activities while having a visual representation, and they are also able to interact with the SmartBoard throughout the lesson as they work to grasp the concepts of area and perimeter." This SmartBoard lesson is a colorful and engaging way for students to learn about area and perimeter while interacting with technology. This activity can also help students apply the concepts of area and perimeter to real-life situations and understand why they are important."

"Each pumpkin patch is (9) feet long and (6) feet wide," says the task. "How big is each patch in square feet?" The task asks 8 similar-format questions (with different numbers for length and width) and allows students to "Write your answers here." The Task's Potential receives a 2 because it does not require students to make connections to concepts or meaning of content (e.g., students could produce the answers procedurally or from memory without making any connections to area, length, width, or square feet) and the task's focus is writing the correct answer.

The PSTs described implementation as follows:

> The following SmartBoard slides in this activity will look at pumpkin patches with different sizes but the same perimeter. Then we'll look at pumpkin patches that are the same size but have a different perimeter. Students will understand that area and perimeter are not always related, and that just because two objects have the same perimeter, they do not have to have the same area, and vice versa.
>
> The following section of the SmartBoard lesson will consist of a problem for students to solve. I'm going to demonstrate an empty pumpkin patch and ask: "If each block of the pumpkin patch counts for one square yard, and 4 pumpkins can fit in each square yard, then how many pumpkins can fit in the patch if the area of the pumpkin patch is 25 blocks?" The blank pumpkin patch will be displayed on the SmartBoard, and students will be able to come up to it and drag and drop pumpkins into each of the squares as they work to solve the problem. Students can also use the manipulatives provided at each table to assist them in solving the problem. Some students may be able to create a formula and solve the problem using worksheets. We will solve the problem on the Smartboard after students have solved it on their own and demonstrate the various ways to find the answer.

The PST group described implementation at the procedure with connections level, and the Described Implementation score is 3. The PSTs want their students to use a variety of strategies and manipulatives to complete the task. The perimeter and area questions require students to engage with and comprehend mathematical concepts. Expected Student responses receive a 3 as well because they were asked to create a formula or use multiple strategies or diagrams to find the correct answer and demonstrate their understanding of perimeter and area.

This case demonstrates how teachers and PSTs can increase the task's cognitive demand during instruction. This case is significant because enacting this task with high level cognitive demands results in various types of student thinking and opens up opportunities for higher order thinking. Furthermore, assigning tasks with a higher cognitive demand to students during instruction can result in higher achievement and conceptual understanding.

Decline of High-Level Cognitive Demands

This case shows how PSTs reduced the cognitive demands of mathematical tasks during implementation, lowering the expected student response from high to low. Carrie is the PST, and she has finished her student teaching. This case is based on a task, implementation reflection, and student work samples submitted as part of her student teaching Showcase Portfolio.

This activity is designed for a 9th and 10th grade Honors Algebra 2 class to create an equation for a quadratic relationship. The goal of this task is to learn how to use a graphing calculator to calculate a quadratic equation that passes through three given points. Using a graphing calculator assists students not only in creating the equation but also in understanding how they will be able to apply this knowledge when working with polynomials.

Figure 6a depicts the task, while Figure 6b depicts the calculator instructions. A mathematical task, as previously stated, can be a single problem or exercise (simple or complex and multi-step) or a collection of related problems or exercises that focus students' attention on a specific mathematical idea (Stein, Smith, Henningsen, & Silver, 2009). This group of related problems is graded as a single task. The Task's Potential receives a 4 because it requires students to engage in complex mathematical thinking and provide an explanation. The final question is "Calculate the revenue if the t-shirts were sold for $4 each, explain what this would mean," and this question earns the task a 4 on the scale.

The school store at Norwin sells T-shirts among other items. The table shows data from the last four years for the price charged for a T-shirt, x, and the total revenue earned from selling them, y.

X	8	10	12	14
Y	1180	1450	1675	1550

1st Observe the table and predict what price should be used to maximize revenue.

2nd Use a graphing calculator to find the best-fitting quadratic model for the data in standard form. (see front board for instructions)

3rd Plot the scatter plot on the calculator

4th Graph the best-fitting quadratic on the calculator

5th Calculate the price of the t-shirts that would maximize the revenue

6th Calculate the total number of t-shirts sold when maximizing the revenue

7th Calculate the revenue if the t-shirts were to be sold for $4 each, explain what this would mean.

Figure 6a: Screenshot of Lesson Activity

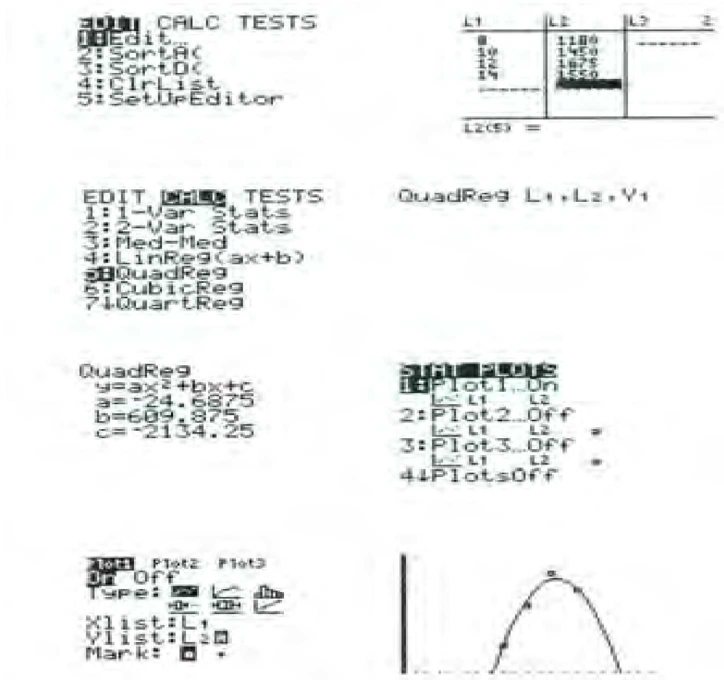


Figure 6b: Screenshot of Calculator Page

Graphing Calculator Instructions for Quadratic Functions

1. STAT Button
   a. 1.Edit
   b. Put x values in
   c. Put y values in
2. 2nd Y= (Stat Plot)
   a. 1. Plot 1
   b. Enter
3. Zoom Button
   a. 9. ZoomStat
4. STAT Button
   a. Right to CALC
   b. 5. QuadReg
5. 2nd STAT (List)
   a. 1. L1
   b. Enter
   c. ,
6. 2nd Stat (List)
   a. 2. L2
   b. Enter
   c. ,
7. VARS Button
   a. Right to Y-VARS
   b. 1. Function
   c. 1. Y1
   d. Enter
8. You should then get your quadratic equation on your screen that passes through those points.

Figure 6c: Screenshot of Calculator Page

Carrie began the class by distributing the day's warm-up problem and handing out the worksheet with the graphic calculator instructions and screen shots on it. This is useful for students to refer to as they work through the problem. Carrie walked around the classroom, assisting students as they worked through this worksheet. She intended to provide opportunities for students to apply critical thinking and problem-solving skills.

However, student response is a 2 because students only provide one-word descriptions or simply solve the task without providing an explanation. Students were expected to plot the scatter plot on the calculator, but there was no evidence of student work with the graphing calculators on their worksheets. Carrie received a 2 for implementation because she intended to use a graphing calculator to teach a quadratic equation, but she describes how limited access to technology in her class made incorporating the graphing calculator into the lesson difficult. Carrie was able to secure laptops for students who did not have their own graphing calculator, and if necessary, they used a website with a graphing calculator at home. Because some students were unable to use graphing calculators in class, they were unable to engage in high-level thinking and reasoning during the lesson.

In this case, technology would have served as a reorganizer, but limited access to the technology prevented students from making connections with representations (High Level Cognitive Demands) that the technology would have illustrated. Furthermore, as stated by Stein and Lane (1996), the decrease in cognitive demands during implementation resulted in moderate student learning.

CONCLUSIONS

Five different case studies were described in this study. These cases discuss how PSTs aimed to implement the same task differently, as well as to maintain, decrease, and increase the level of cognitive demands during the described implementation. These cases can assist teacher educators and PSTs in understanding how to design and implement instructional activities and technology within the context of mathematics for students' higher mathematics learning and success. These examples are significant because the selection and implementation of instructional tasks has an impact on students' mathematical understanding. Maintaining the cognitive demand of instructional tasks through task implementation, as defined by Stein and Lane (1996), resulted in higher student achievement.

The study's recommendations can be used as a guide in mathematics teacher preparation programs. The findings of this study can help mathematics teacher educators prepare PSTs to use technology to support students' high level mathematical thinking by providing a framework (e.g., attention to cognitive demands) and examples. While the focus of this study was on PSTs, considering cognitive demands when planning instructional activities is also a useful framework for classroom teachers. Similarly, while this study focused on mathematics content, the findings have the potential to guide mathematics or instructional technology courses in universities that are preparing PSTs to incorporate technology into instruction in ways that support students' learning.

It is critical to train PSTs to use technological tools in ways that support students' high-level thinking in any subject. Teacher educators should be aware of the importance of attending to cognitive demands when using technology as a teaching and learning tool, and future teachers should be prepared with this goal in mind. The study could provide resources and/or materials for mathematics teacher educators to consider various levels of cognitive demands of tasks in and outside of mathematics.

Several studies found that the use of technology had a positive influence on student achievement (Bebell & Kay, 2010; Bebell & O'Dwyer, 2010; Higgins, Huscroft-D'Angelo, & Crawford, 2019; Ran, Kim, & Secada, 2022; Shapley, Sheehan, Maloney, & Caranikas-Walker, 2010; Suhr, Hernandez, Grimes, & Warschauer, 2010). Because they grew up in a technologically advanced world, students in the classroom are digital natives (Prensky, 2001). Today's PSTs can integrate technology into their lesson plans and indicate that they are open to the idea, but they need guidance to do so effectively. This guidance is a blend of technological, pedagogical, and content knowledge. Not only must teacher education programs address pedagogical and content knowledge, but also the use of technology within specific pedagogy (e.g., learner-centered classrooms) and content (e.g., mathematics). Method courses provide future teachers with pedagogical content knowledge while also providing opportunities for PSTs to increase their technology knowledge within the context of pedagogical and content-related goals. Mathematics teacher educators should help PSTs effectively design technology-based instruction, help PSTs integrate technology into lesson plans, and provide opportunities for PSTs to use technology in field experience or student teaching classrooms. According to the findings of this study, one productive path would be to provide guidance to PSTs on how to maintain or increase the level of cognitive demands.

Classrooms, especially for PSTs, are complex environments. Prospective teachers need more opportunities to design and implement technology-based instructional activities that support students' learning. According to Haryani and Hamidah (2022), technology-integrated worksheets allow students to explore content rather than simply answering questions, increasing student engagement and understanding in discussions. PSTs, in particular, require opportunities to teach these activities as part of teacher preparation programs, field experiences, and student teaching in order to be prepared and comfortable incorporating technology into their future classrooms. The use of technology by PSTs is unlikely to be successful unless it is practiced prior to and during student teaching. PSTs, for example, can practice by developing and delivering technology-based instructional activities that combine technology, pedagogy, and content knowledge. As a result, teacher education programs should provide opportunities for PSTs to incorporate technology into methods courses and student teaching placements. The ultimate goal is for PSTs to apply what they've learned in their future classroom settings. The level of cognitive demand for mathematical tasks is implemented at a lower level than predicted during implementation (Boston, Candela, & Dixon, 2019; Henningsen & Stein, 1997). In practice, high-level tasks in textbooks or lesson plans should be reduced (Dede, Ünal, &Ylmaz, 2023). Because most mathematical tasks in activities and implementations have a low cognitive demand (Dede, Ünal, &Ylmaz, 2023; Reçber & Sezer, 2018), this study will shed light on how mathematical tasks are designed and integrated in practice.

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Appendix A

Academic Rigor 1: Potential of the Task

<table>
<tr><td colspan="3">Instructional Quality Assessment (IQA) in Mathematics Rubrics (Boston, 2012)</td></tr>
<tr><td colspan="3">AR1: Potential of the Task</td></tr>
<tr><td rowspan="2">High-Level Cognitive Demands</td><td></td><td>The task has the potential to engage students in exploring and understanding the nature of mathematical concepts, procedures, and/or relationships, such as (from Stein, et al., 2009):
Doing mathematics: using complex and non-algorithmic thinking (i.e., there is not a predictable, well-rehearsed approach or pathway explicitly suggested by the task, task instructions, or a worked-out example); or
Procedures with connections: applying a broad general procedure that remains closely connected to mathematical concepts.
The task must explicitly prompt for evidence of students’ reasoning and understanding. For example, the task MAY require students to:
solve a genuine, challenging problem for which students’ reasoning is evident in their work on the task;
develop an explanation for why formulas or procedures work;
identify patterns;…justify generalizations based on these patterns;…</td></tr>
<tr><td></td><td>The task has the potential to engage students in complex thinking or in creating meaning for mathematical concepts, procedures, and/or relationships. However, the task does not warrant a “4” because:
the task does not explicitly prompt for evidence of students’ reasoning and understanding.
students may need to identify patterns but are not pressed to form or justify generalizations;
students may be asked to use multiple strategies or representations but the task does not explicitly prompt students to develop connections between them;…</td></tr>
<tr><td rowspan="2">Low –Level Cognitive Demands</td><td></td><td>The potential of the task is limited to engaging students in using a procedure that is either specifically called for or its use is evident based on prior instruction, experience, or placement of the task…. The task does not require students to make connections to the concepts or meaning underlying the procedure being used… (e.g., practicing a computational algorithm).</td></tr>
<tr><td></td><td>The potential of the task is limited to engaging students in memorizing or reproducing facts, rules, formulae, or definitions…</td></tr>
</table>

Appendix B

Academic Rigor 2: Implementation of the Task

Implementation of the Task (Boston, 2012)	
	Students engage in using complex and non-algorithmic thinking or by exploring and understanding the nature of mathematical concepts, procedures, and/or relationships.
	Students engage in complex thinking or in creating meaning for mathematical proceduresand concepts BUT the problems, concepts, or procedures do not require the extent of complex thinking as a "4"; OR The "potential of the task" was rated as a 4 but students only moderately engage with thehigh-level demands of the task .
	Students engage with the task at a procedural level. Students apply a demonstrated orprescribed procedure. Students may be required to show or state the steps of their procedure, but are not required to explain or support their ideas. Students focus on correctly executing a procedure to obtain a correct answer.
	Students engage with the task at a memorization level. Students are required to recallfacts, formulas, or rules (e.g., students provide answers only). OR The task requires no mathematical activity.
N/A	Reason:

Appendix C

Academic Rigor 3: Expected Student Response

Expected Student Response (Boston, 2012)	
	The expected student response provides evidence of students' mathematical thinking and reasoning (such as multiple representations or strategies, diagrams, etc.)AND an explanation is explicitly required.
	The expected student response provides evidence of students' mathematical thinking and reasoning (such as multiple representations or strategies, diagrams, etc.) BUTno explanation is required.
	The expected student response is a computation or procedure,…or procedural explanationsuch as "Show your work." Students are not required to demonstrate connections to mathematical concepts in theirresponse to the task, even if task itself provided opportunities for connections.
	Students *are asked to* provide brief numerical or one-word answers (e.g., fill in blanks,provide only the result or answer).
N/A	Reason: