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K-8 Pre-Service Teachers' Technology Integration in Mathematics: Perspectives and Anticipated Practices

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Abstract: This qualitative, phenomenological study sought to examine kindergarten through eighth-grade pre-service teachers' (N = 19) perspectives on technology integration within the context of mathematics. Topics of primary interest were pre-service teachers' knowledge of technology integration, their questions/concerns regarding technology integration, their anticipated technology integration practices, and the impact of technological resources on mathematics instruction for their proposed uses of technology. Both the SAMR and PICRAT models informed the methodology of this study. Data were collected from responses to open-ended prompts as part of a mathematics methods course and analyzed with both *a priori* (i.e., SAMR and PICRAT) and emergent coding. Findings showed that responses were most aligned with interactive, amplification level of the PICRAT model and the augmentation level of the SAMR model, in which pre-service teachers often described students' use of mathematical games. Additionally, this study found that pre-service teachers reported limited knowledge of technology integration, have questions/concerns related to when and how to integrate technology, and anticipate that they will integrate technology into their future classrooms relatively frequently. Implications of the findings for both researchers and teacher educators are discussed, as well as recommendations for future research.

Keywords: Pre-Service Teacher, Perspectives, PICRAT, SAMR, Technology Integration.
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Introduction

Technology Integration in Mathematics

In the increasingly digitized educational landscape of recent years, integrating technology into instructional practice should no longer be seen as an optional enhancement but as a fundamental component of effective teaching. In mathematics education, digital tools afford dynamic and interactive representations of mathematical ideas, enabling learners to engage with concepts and procedures in ways that transcend traditional paper-and-pencil methods. As technology becomes more commonplace in the world of education, it is crucial that pre-service teachers (PSTs) are adequately prepared to leverage technology use in a way that may enhance their mathematics instruction and/or their students' mathematics learning. Yet, despite the centrality of technology-rich instruction, there remains limited understanding of how PSTs, particularly at the kindergarten through eighth grade (K-8) level, perceive, plan for, and intend to meaningfully integrate these tools into their mathematics practice.

The integration of technology into K-8 mathematics has been associated with a variety of benefits to students, teachers, and schools. Though various technological resources exist, particularly popular resources in K-8 mathematics are virtual manipulatives and mathematical games. Virtual manipulatives, defined as "an interactive, technology-enabled visual representation of a dynamic mathematical object, including all of the programmable features that allow it to be manipulated, that presents opportunities for constructing mathematical knowledge" (Moyer-Packenham & Bolyard, 2016, p. 3), have been shown to increase K-8 students' conceptual knowledge of several mathematics topics (Reimer & Moyer, 2005; Suh & Moyer, 2007), positive attitudes toward mathematics (Lee & Chen, 2015; Sen et al., 2017), confidence in mathematics (Yuan et al., 2010), and feelings of competency (McLeod et al., 2013). K-8 students with disabilities have benefitted from virtual manipulative use as well, demonstrating increased rates of learning (Root et al., 2017), greater accuracy (Bouck et al., 2014), and faster independence (Bouck et al., 2017; Bouck et al., 2018). Mathematical games, such as those offered by Math Playground (https://www.mathplayground.com/), have been shown to increase K-8 students' achievement (e.g., pre- and post-test design) regarding multiplication (Kiger et al., 2012), adaptive number knowledge, arithmetic fluency, and pre-algebra knowledge (Brezovszky et al., 2019). Technological resources also benefit teachers and schools, as many are free to access, available for use outside of the classroom, and decrease in-class time spent distributing and gathering materials during lessons (Moyer et al., 2002).

Due to these benefits, it is imperative that PSTs are competent in technology integration upon degree completion. However, sufficiently preparing PSTs to integrate technology into their future classrooms has proven to be a challenging task for teacher education programs. Historically, a common approach implemented by teacher education programs has been adding the requirement of a stand-alone educational technology course—an approach that 85% of institutions have adopted (Kleiner et al., 2007)—which has not proven to be especially effective (Brush et al., 2003, Zipke, 2018). These courses often lack content-specific contexts and classroom practice opportunities, as just 32% of institutions provide learning experiences where PSTs deliver technology experiences within elementary classrooms (Rose et al., 2017). An alternate approach is to has been to integrate technology use throughout various methods courses (Austin & Kosko, 2022; Trainin et al., 2018). Despite these efforts to integrate technology into PSTs' teacher training programs, many PSTs feel unprepared to effectively integrate technology on their first day of in-service teaching (Tondeur et al., 2012). Research has uncovered several factors that explain PSTs' feelings of unpreparedness, including insufficient access to technology (Dawson, 2008), lack of technology skills (Teo, 2009), negative attitudes toward technology integration, lack of confidence in their ability to integrate technology, and the belief that their competence may be undermined due to students potentially having more knowledge about technology (Crompton, 2015). More so, prior studies have noted that PSTs have a limited understanding in meaningfully using technology to improve mathematics instruction (Cullen & Green, 2011; Wachira et al., 2008). This study sought to further explore PSTs' feelings of unpreparedness by examining their perspectives on technology integration within the context of K-8 mathematics—including their knowledge, questions/concerns, anticipated practices, and proposed technology uses—as gaining additional information regarding PSTs' perspectives on technology integration may prove beneficial to teacher education programs, current PSTs, and future PSTs.

This study aimed to explore PSTs' perspectives on technology integration within the context of the K-8 mathematics classroom, as well as their anticipated practices for such integration. Understanding PSTs' perceptions of technology integration is important not only because they will soon be tasked with enacting such practices in real classrooms, but also because their views can offer critical insights into how teacher preparation programs might more strategically support their development. As PSTs engage with technology tools in learning to teach mathematics, their evolving perspectives can illuminate the kinds of support and experiences needed to help them make thoughtful, student-centered, and pedagogically sound decisions (Liu et al., 2024).

This study also aimed to closely examine two widely used models of technology integration: SAMR (Substitution, Augmentation, Modification, Redefinition) (Puentedura, 2003) and PICRAT (Passive, Interactive, and Creative—Replacement, Amplification, and Transformation) (Kimmons et al., 2020). Exploring teachers' perspectives through the lens of these theoretical models informs the coherent design of theory-to-practice connections in teacher education programs. We argue that such understanding is especially valuable for mathematics teacher educators, as it sheds light on how the SAMR and PICRAT models can bridge both the planning and enactment phases of instruction. By doing so, these models help PSTs design technology-rich learning experiences that deepen student understanding and promote active engagement in mathematics.

While the SAMR model focuses on how technology transforms instructional tasks, the PICRAT model adds a critical layer by incorporating both student engagement and teacher intent. Each model captures distinct but complementary aspects of technology use. Relying solely on the SAMR model may overlook students' learning experiences, while using only the PICRAT model may miss the depth of task transformation. Examining both through the lens of PSTs' perspectives enables a more holistic understanding of technology integration that is pedagogically meaningful and responsive to learners.

Theoretical Framework

The primary theoretical perspectives used to guide this study were Puentedura's (2003) Substitution, Augmentation, Modification, and Redefinition (SAMR) model and Kimmons et al.'s (2020) Passive, Interactive, and Creative—Replacement, Amplification, and Transformation (PICRAT) model. As both the SAMR and PICRAT models are frameworks through which the impact of technology integration on instruction may be evaluated, this study provides a comparison of the two frameworks. These technology integration frameworks were selected for comparison due to the popularity of the SAMR model (e.g., Hamilton et al., 2016) and the teacher-education-focused design of the PICRAT model (Kimmons et al., 2020).

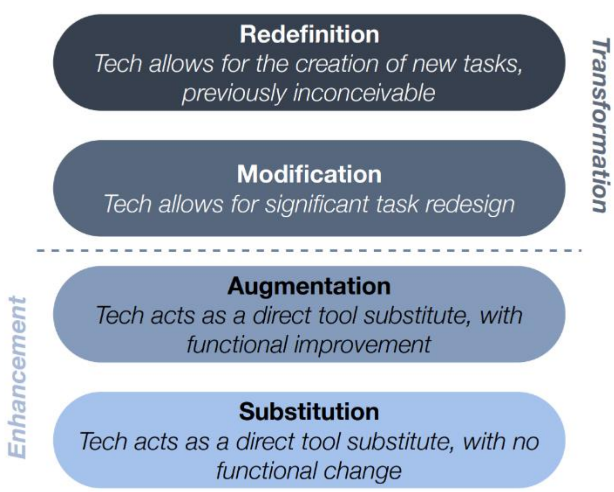
The SAMR Model

Puentedura's (2003) SAMR model offered a means by which the impact of technological resources on instruction from the perspective of the teacher may be categorized. Figure 1 highlights the four hierarchical levels of the SAMR model in respect to the impact that the integration of technology has on instruction. Technology integration aligned with the first two levels—substitution and augmentation—enhances mathematics instruction in some way but does not provide a significant transformation. The primary difference between these two levels is that, at the augmentation level, technological resources provide some amount of functional improvement. Instruction experiences a transformation when technology integration aligns with either the modification or redefinition levels. While technological resources have a significant impact on instructional tasks at both of these levels, these two levels are distinguished by the redefinition level's affordance of implementing tasks that are inconceivable without the use of technology. Within the mathematics context of graphing functions, Dorman (2018) provided examples for each level of the SAMR model:

> At the substitution level, instead of printing off paper copies of the worksheet, an instructor could make the worksheet available online. At the augmentation level, students could complete the same questions on a Google Form, and the instructor could capture the answers for individual students to check for understanding. … At the modification level, … students could work in groups to analyze the different characteristic of functions as they graph them. Then, students could video record the characteristics and steps of how to graph functions. The video could be uploaded to a classroom website so that students can use it as a tutorial or study aid. At the redefinition level, students could create an online portfolio of all types of functions, and their graphs could include real-world applications that are modeled by the functions. (para. 3)

Figure 1

The SAMR Model



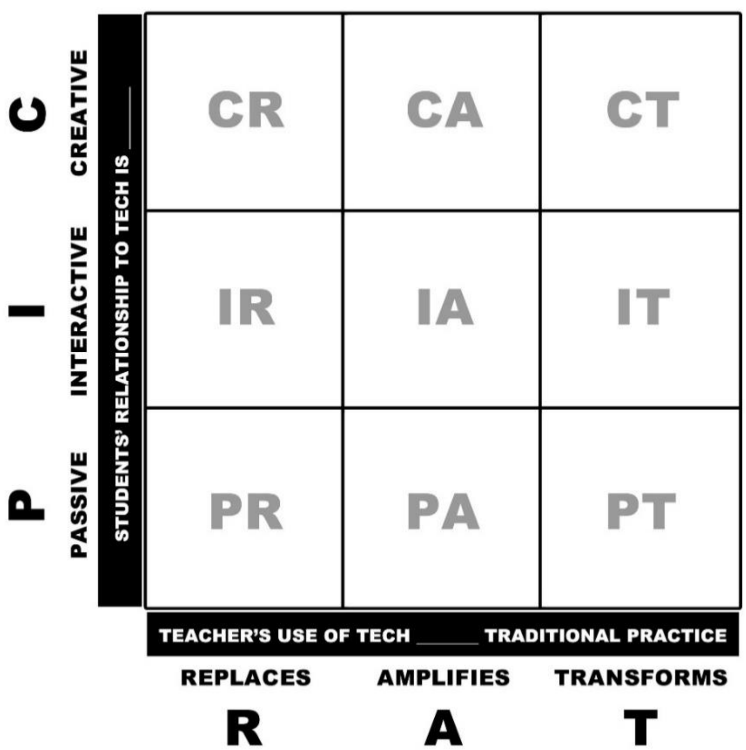
Note. (Puentedura, 2003)

An example of the SAMR model's use is presented by Wijaya and colleagues (2021), where the SAMR model was used as a lens to evaluate instructors' abilities to integrate technology into postsecondary mathematics instruction during the COVID-19 pandemic. Wijaya and colleagues found evidence of various levels of technology integration in this study but reported that instructors' use of technology was mostly at the augmentation level. In this study, the researchers also used the SAMR model as a lens for interpreting technology integration within the mathematics classroom, though within the context of PSTs at the K-8 level.

While the SAMR model is often utilized in technology integration research, the model is not without criticism. In fact, a portion of the rationale to create the PICRAT model was Kimmons and colleagues' critique of the SAMR model and other existing technology integration models. Specifically, Kimmons et al. (2020) critiqued the boundaries of the four levels of the SAMR model, stating that the definitions of each level are unclear and that the distinctions between levels may be too specific and, therefore, not meaningful to teachers. Additionally, the SAMR model does not account for what students do or learn during instruction, as "student activities…are not explicit or inherent in each level's definition" (Kimmons et al., 2020, p. 182). Thus, the PICRAT model addresses these concerns by: (a) clearly defining each level of technology integration, (b) decreasing the number of levels to create more meaningful boundaries, and (c) integrating an additional perspective to focus more on students' relationship to the technology.

Figure 2

The PICRAT Model



Note. (Kimmons et al., 2020)

The PICRAT Model

Similar to the SAMR model, the PICRAT model (Kimmons et al., 2020) provided a lens through which the impact of technology on instruction from the perspective of the teacher may be analyzed. Notably, the PICRAT model differs from the SAMR model by also providing a lens for examining this impact from the perspective of the student. The PICRAT model is organized into a hierarchical matrix (Figure 2) composed of two distinct portions. The first, PIC, refers to students' relationship to the technology—including passive learning, interactive learning, and creative learning (Papert & Harel, 1991). The second, RAT (Hughes et al., 2006), refers to the impact of technology on teachers' pedagogical practices—including replacement, amplification, and transformation. Thus, the PICRAT model addresses the impact of technology on instruction from the perspective of both students and teachers. An example of the PICRAT model's use is presented by Sung and colleagues (2024), where the PICRAT model was used as a lens to analyze technology-integrated activities in kindergarten through twelfth grade classrooms. Sung and colleagues observed higher frequencies of technology use within the passive and replacement levels and lower frequencies of technology use within the creative and transformation levels for all grade levels. The PICRAT model was applied in a similar fashion in this study in order to further explore PSTs' perspectives on technology integration.

Examples of passive learning, the first level of PIC, described by Kimmons et al. (2020) include listening, observing, and reading. In the context of technology use, passive learning includes activities such as reading notes on a PowerPoint slide or watching a YouTube video. When passively learning, students receive information but neither interact with nor create information. The second level of PIC, interactive learning, occurs when students are able to engage with the material with active behaviors such as exploration, experimentation, and collaboration. Though students are interacting with the technological resource at this level, the presence of structure within the resource restricts students' ability to create. Thus, the "learning is largely structured by the technology rather than by the student" (Kimmons et al., 2020, p. 186). Examples of interactive learning with technology include playing virtual games or exploring a dynamic area model applet on GeoGebra. In each of these examples, the students interact with the technology to direct aspects of their learning, but the structure of the resources limit the scope of students' learning to a specific context (e.g., playing virtual games that follow a preset or adaptive progression, exploring a GeoGebra applet that only examines areas of rectangles, etc.). Creative learning, the third level of PIC, is highlighted by students' ability to use a platform to "construct learning artifacts that instantiate learning mastery" (Kimmons et al., 2020, 186). One might creatively learn with technology by editing videos, writing computer code, or constructing virtual figures with dynamic software. Creative learning bypasses the limiting structures of technology that exist in activities that enable interactive learning, allowing students to "directly drive the learning as they produce artifacts…and iteratively solve problems by applying the technology to refine their content understanding" (Kimmons et al., 2020, p. 186).

The first level of RAT, replacement, is described by Kimmons et al. (2020) as replacing a physical resource with a technological resource in a way that does not improve either teachers' pedagogical practices or students' learning outcomes. This level is very similar to those described in other technology integration models, such as the substitution level of the SAMR. Examples include using digital notes (e.g., Microsoft Word, Google Docs, etc.) instead of physical notes, an interactive whiteboard rather than a chalkboard, or an educational video as a replacement to a lecture. Though replacement is not poor practice by default, Kimmons et al. noted that this strategy should not be the overall goal of technology integration. Amplification, the second level of RAT, occurs when the use of technology allows the teacher to enhance pedagogical practices or students' learning outcomes. This use of technology "improves upon or refines existing practices, but…may not allow teachers to fundamentally rethink and transform their thinking" (Kimmons et al., 2020, p. 187). Examples include gathering data with a technological instrument or using features of a word processor to improve collaboration. The third level of RAT, transformation, uses technology to enable a previously inconceivable pedagogical practice. Examples include analyzing data with online simulations or interviewing an expert with a video conferencing service. It is worth noting that the distinction between the amplification and transformation levels has been disputed for decades due to its subjectivity, as highlighted in the Clark-Kozma debate (Clark, 1994; Kozma, 1994).

As highlighted in Figure 2, the PICRAT model is utilized as a two-dimensional matrix in order to evaluate the impact of technology on instruction in relation to both teachers and students. Each use of technology is evaluated in relation to each dimension. For example, an activity in which students complete an online mathematics assessment on individual devices aligns with the interactive, amplification (IA) level of the matrix. This is because the students are interacting with the technology, and the use of technology amplifies the teacher's practice in some way (e.g., more efficient, immediate feedback provided to students).

Comparison of Models

Perhaps the greatest benefit of the PICRAT model in comparison to the SAMR model is the inclusion of students' relationship to the technology utilized during instruction as identified by the PIC portion of the model. While the SAMR model excludes the perspective of the student, the PICRAT model allows for an examination of whether students are using technological resources passively, interactively, or creatively. The distinctions between students' passive, interactive, or creative use of technology are directly related to their learning outcomes, as lasting and meaningful learning occurs best through interactive and, more so, creative uses of technology (Kennewell et al., 2008; Papert & Harel, 1991). Thus, the inclusion of a framework for examining students' relationship to technology in the PICRAT model enhances the analysis of technology integration by providing a broader understanding of the impact of technology on both instruction and students' learning outcomes.

Research Questions

The intent of this study was to examine current K-8 PSTs' perspectives on technology integration in mathematics. As highlighted in prior research, PSTs often feel unprepared to effectively integrate technology (Tondeur et al., 2012), lack confidence in integrating technology (Crompton, 2015), and have a limited understanding in using technology to improve mathematics instruction (Cullen & Greene, 2011; Wachira et al., 2008). The aforementioned challenges associated with PSTs' integration of technology into their classrooms inform the primary areas of interest in this study: (a) PSTs' knowledge of technology integration, (b) PSTs' questions/concerns regarding technology integration, (c) PSTs' anticipated technology integration practices, and (d) the impact of technological resources on mathematics instruction in PSTs' proposed uses of technology. In addition, this study sought to compare the utility of two distinct technology integration frameworks, the SAMR model (Puentedura, 2003) and the PICRAT model (Kimmons et al., 2020), to guide future research on technology integration. Thus, the research questions in this study included the following:

Q1. What knowledge of technology integration in mathematics do K-8 PSTs possess as viewed through the lens of both the SAMR and PICRAT models?

Q2. What questions/concerns do K-8 PSTs have regarding technology integration in mathematics as viewed through the lens of both the SAMR and PICRAT models?

Q3. What are K-8 PSTs' anticipated technology integration practices for their future mathematics classrooms as viewed through the lens of both the SAMR and PICRAT models?

Q4. For K-8 PSTs' proposed uses of technology in mathematics, how would the technological resource impact mathematics instruction as viewed through the lens of both the SAMR and PICRAT models?

Methods

Research Design

This study employed the paradigm of social constructivism—seeking to understand PSTs' perspectives on technology integration by learning about their knowledge of, questions/concerns about, and anticipated practices for technology integration while recognizing the impact of both social interactions and historical/cultural norms (Creswell & Poth, 2017). Through the lens of social constructivism, a phenomenological approach was applied to describe PSTs' common meaning of the concept of technology integration within the context of mathematics (Creswell & Poth 2017). Thus, this study gathered individual responses to prompts and artifacts to describe the shared understandings of a homogeneous group of K-8 PSTs regarding their perspectives on technology integration in mathematics.

Application of Theoretical Perspectives

Both the SAMR model and the PICRAT model guided the methodological approach of this study. Data collection was informed by these two perspectives as we sought to create and pose prompts from which PSTs' responses would provide insight regarding PSTs' perspectives on technology integration in relation to both students and teachers. The SAMR and PICRAT models were also utilized in the data analysis, as each model was individually applied as an *a priori* codebook when examining PSTs' responses. Lastly, these models were used as a lens through which PSTs' perspectives on technology integration were interpreted when discussing the findings and their implications.

Context, Sample, and Sampling Procedures

This study was conducted at a large postsecondary institution in the Northwest region of the United States and approved by its Institutional Review Board. Participants (*N* = 19) were recruited via convenience sampling from an undergraduate mathematics methods course (i.e., K-8 Math Methods) during the spring semester of 2020. All participants were PSTs enrolled in an elementary education program that leads to initial licensure for teaching grades K-8. Most participants were nearing completion of their four-year teaching degree, as the majority would be student teaching in the upcoming fall 2020 semester. Thus, the population of this study was PSTs in their third or fourth year of a teacher training program who are enrolled in a mathematics method course at the research site. Of the PSTs recruited for this study, 19 of 24 (79.2%) consented that their responses may be analyzed for research purposes. The recruited sample did not allow for an analysis based on demographic factors (e.g., gender, race/ethnicity, etc.) because the vast majority of PSTs in the sample were White females in their third or fourth year of the elementary education program. Thus, demographic information was not gathered in this study due to the lack of variance in such factors.

Table 1

Open-Ended Prompts

Prompt Timing	Prompt
Day one	
Entrance prompt (P1)	What do you know about using educational technology in the mathematics classroom?
Exit prompt (P2)	What questions/concerns do you have about using educational technology in the mathematics classroom?
Day two	
Entrance prompt (P3)	How frequently do you plan on using educational technology in the mathematics classroom?
Exit prompt (P4)	Find one resource (including the URL) and answer the following questions: (a) For what grade level and CCSS (Common Core State Standard) would the resource be appropriate to use? (b) Explain how this resource might benefit a lesson (e.g., impact on student learning, more efficient than ‘traditional’ strategies, etc.).
End-of-unit assessment	
First prompt (P5)	Locate one resource (including the URL) and describe how you might use this resource to assess understanding in your future classroom.
Second prompt (P6)	What do you think is the most practical application of technology in K-8 mathematics, and why?

Participants engaged in a two-day lesson (two 75-minute periods) on technology integration in K-8 mathematics taught by the first author during the second week of the semester. The design of the lesson was informed by Foulger et al.’s (2017) recommendations regarding teacher educator technology competencies. The first day of the lesson included an introduction to and exploration of technological resources relevant to mathematics education (i.e., NCTM Illuminations, Shodor Interactivate, Desmos, GeoGebra, Khan Academy, Math Playground, and the National Library of Virtual Manipulatives). These resources were introduced in a way that modeled the alignment of K-8 mathematics content with both pedagogy and technology. During the second day of the lesson, PSTs discussed potential benefits and detriments of technology integration, as well as pedagogical practices that are appropriate when utilizing a technological resource in the classroom. At the end of the second day of the lesson, PSTs engaged in a collaborative activity in which they designed mathematical tasks which utilized technological resources. Following the two-day lesson, PSTs were asked to read Johnson et al.'s (2012) teaching article titled *Virtual Manipulatives to Assess Understanding*. A whole-group discussion of this article at the beginning of the next course meeting marked the culmination of the two-day lesson on technology integration.

Data Collection

Data were collected from activities associated with the aforementioned two-day lesson. Notably, data collection occurred in mid-January of 2020—just two months prior to the transition to online instruction at the research site due to the COVID-19 pandemic. PSTs were asked to respond to several prompts prior to, during, and following the two-day lesson. Open-ended prompts were posed to PSTs in the form of two entrance prompts, two exit prompts, and two prompts on an end-of-unit assessment (Table 1). PSTs submitted their responses to the researchers online with a learning management system. Due to absences, early departures, and late arrivals, the day one exit prompt (P2) had one missing response, the day two entrance prompt (P3) had two missing responses, and the day two exit prompt (P4) had one missing response. PSTs with missing responses were not excluded from this study, so the sample size ranges from 17 to 19 for each research question and the total number of PSTs' responses examined was 110. Responses were first downloaded as individual files and then organized into a Microsoft Excel spreadsheet in preparation for analysis. The files and spreadsheet were securely stored on the lead researcher's personal computer. Any information that could be used to identify PSTs was redacted and PSTs' names was replaced with identification numbers.

Data Analysis

Research questions were analyzed through two lenses—first using both the PICRAT and SAMR models as *a priori* codebooks and then utilizing emergent coding to enable a less-restrictive analysis (Creswell & Poth, 2017). Thus, for the first analysis, each researcher independently coded each PST's response to each prompt as passive, interactive, creative, replacement, amplification, and/or transformation (PICRAT) and substitution, augmentation, modification, and/or redefinition (SAMR). It is worth noting that some of the PSTs' responses were coded as multiple PICRAT and/or SAMR levels in cases where multiple topics were discussed. Next, the first three research questions were analyzed by utilizing emergent coding aligned with the theme-identifying strategy of "repetition" in which themes are identified on the basis of the frequency at which a topic occurs and reoccurs (Ryan & Bernard, 2003). In alignment with the emergent coding process outlined by Creswell and Poth (2017), the researchers first established a coding platform (i.e., Microsoft Excel spreadsheet) and developed a list of preliminary codes based on the theme-identifying strategy of "repetition" for each prompt used to examine the first three research questions. As an example of using repetition to develop preliminary codes, sample PST responses to P1 included: *Not much…*; *I don't know a whole lot…*; *Seen some online resources but I don't remember what they are called…*; *In terms of* *math education, not a lot…*; and *I don't know any specifically having to do with math*. This commonly mentioned notion of lacking knowledge regarding technology integration in the mathematics classroom led the researchers to establish the preliminary code *Lack of Knowledge*. After identifying preliminary codes, each researcher independently applied this preliminary codebook to each PST's responses to each prompt (i.e., cross-coding). The researchers then compared their coding for consistency, assessed the interrater reliability (IRR), discussed whether any codes ought to be combined into broader categories, and made revisions after discussion as deemed necessary. Though there are several options for representing IRR, the researchers followed the recommendation of Creswell and Poth (2017) to represent IRR as percent agreement (e.g., what percent of codes were the same for both coders). According to McHugh (2012), percent agreement is an appropriate measure when little guessing is likely to exist among the raters and is often a preferable measure since it is more directly interpretable than Cohen's kappa. Upon completion of these analyses, the researchers examined the first research question with P1, the second research question with P2, the third research question with both P3 and P6, and the fourth research question with both P4 and P5.

Results

Interrater Reliability

Following the finalization of the researchers' coding, the IRR was calculated as percent agreement for the PICRAT model, the SAMR model, and the emergent coding for each of the six prompts. The IRRs for each prompt were then used to calculate the mean weighted IRR to represent the overall percent agreement for the PICRAT model, the SAMR model, and the emergent coding for all PSTs' responses analyzed in this study. The researchers attained a mean weighted IRR of 80.9% (89/110) for the PICRAT model, 80.0% (88/110) for the SAMR model, and 86.3% (63/73) for the emergent coding. While the mean weighted IRR for the PICRAT and SAMR models were nearly identical, it is worth noting that the mean weighted IRR for the PIC portion of the PICRAT model was 91.8% (101/110) while the mean weighted IRR for the RAT portion was 87.3% (96/110). It is also worth pointing out that the number of PSTs' responses for the emergent coding differs from the PICRAT and SAMR models since emergent coding was not utilized for P3 or P4. Based on the minimum IRR of 80% recommended by Creswell and Poth (2017), the results reported in this study are acceptable.

Knowledge of Technology Integration

The first research question was examined with PSTs' responses (n = 19) to P1. PSTs' responses were coded using the *a priori* codebooks of both the PICRAT and SAMR models as well as emergent coding to identify themes in order to assess PSTs' technology integration knowledge. Several PSTs' responses did not include enough information to be confidently coded by the researchers in alignment with the *a priori* codebooks, as nine responses (47.4%) did not receive a code regarding the PICRAT model and four responses (21.1%) did not receive a code regarding the SAMR model.

In their responses, PSTs most frequently (*n* = 7, 36.8%) discussed topics aligned with the PICRAT level of IA (interactive, amplification). Students' interactive relationship to technology was often highlighted when discussing how mathematical games and websites can be used by students to practice mathematics problems related to content that was introduced earlier in a lesson. When describing students' interactive use of technology, most PSTs discussed ways in which the use of technology might amplify either teachers' pedagogical practices or students' learning outcomes (i.e., enabling differentiation or increasing students' engagement in the content) while some described technology use that merely replaced non-technological classroom practices (IR—interactive, replacement; *n* = 3, 15.8%). PSTs' responses that aligned with the PICRAT levels of PR (passive, replacement; *n* = 3, 15.8%) or PA (passive, amplification; *n* = 2, 10.5%) were somewhat common. In these responses, PSTs discussed uses of technology where students were passively consuming information (i.e., reading content or watching videos). Some PSTs discussed how students' passive use of technology might amplify instruction (i.e., increasing student interest), but most discussed technology use that replaced non-technological classroom practices without an apparent impact on either teachers' pedagogical practices or students learning outcomes. Very few PSTs' responses aligned with either CA (creative, amplification; *n* = 1, 5.3%) or CT (creative, transformation; *n* = 1, 5.3%). In the two responses where PSTs discussed students' use of technology for creative purposes, one use of technology amplified instruction (i.e., completing projects) while the other transformed instruction (i.e., mathematical modeling and using technology for research). On P1, no PSTs' responses were coded as PT (passive, transformation); IT (interactive, transformation); or CR (creative, replacement). Frequencies and examples of responses from PSTs that align with each level of the PICRAT model are displayed in Table 2.

Table 2

PICRAT Coding: PSTs' Knowledge of Technology Integration

Level	*n*	%	PSTs' Responses
Passive, Replacement (PR)	3	15.8%	• Khan Academy for math videos • My [cooperating teacher] last year used Khan Academy for when students finished work early
Passive, Amplification (PA)	2	10.5%	• I'm familiar with the app that will solve math problems and explain them
Interactive, Replacement (IR)	3	15.8%	• Google classroom as a way to collaborate
Interactive, Amplification (IA)	7	36.8%	• One of the stations during math time was on the computer where they did math that was at their level • Learning games that involve math concepts/strategies
Creative, Amplification (CA)	1	5.3%	• It can be an awesome way for students to complete projects
Creative, Transformation (CT)	1	5.3%	• GeoGebra, Tinkerkad, graphing calculators, math modeling – use technology for research, learning glass – record math lessons

Similar to the results of the PICRAT coding, most PSTs' responses were coded as either augmentation (*n* = 10, 52.6%) or substitution (*n* = 6, 31.6%) when using the SAMR model. More than half of PSTs' responses described uses of technology that augmented instruction, where the technological resource acts as a substitute for a physical tool and the use of technology provides some level of functional improvement to instruction, such as allowing students to complete practice problems using mathematical games. About a third of PSTs' responses described uses of technology in which the technological resource acts as a substitute without any functional improvement to instruction, such as replacing a whiteboard with an interactive whiteboard or replacing instruction with mathematical videos. Only one PST (5.3%) discussed technology use is a way that aligned with modification when describing how technology can be used for both mathematical modeling and research purposes. Frequencies and examples of responses from PSTs that align with each level of the SAMR model are displayed in Table 3.

Table 3

SAMR Coding: PSTs' Knowledge of Technology Integration

Level	*n*	%	PSTs' Responses
Substitution	6	31.6%	• Khan Academy for math videos • Smartboards, calculators, and document cameras • My [cooperating teacher] used Khan Academy for when students finished work early
Augmentation	10	52.6%	• Math based computer games to give students practice • Using technology can enhance a lesson's effectiveness • Programs can automatically adjust to students' levels as they progress
Modification	1	5.3%	• GeoGebra, Tinkerkad, graphing calculators – use technology for research, learning glass – record math lessons

The emergent coding analysis produced five themes regarding K-8 PSTs' knowledge of technology integration in mathematics: (a) general lack of knowledge, (b) various pedagogical considerations, (c) knowledge of specific technological resources, (d) knowledge of mathematical games, and (e) knowledge of specific technological devices. Frequencies and examples of responses from PSTs that motivated each emergent coding theme are displayed in Table 4. Over one third of the PSTs (*n* = 7, 36.8%) reported that they did not have much knowledge in regard to technology integration in mathematics. While most PSTs were able to provide some information about integrating technology into education in general, they were less knowledgeable about technology integration in the specific context of K-8 mathematics. In their responses, about one third of the PSTs (*n* = 7, 36.8%) referenced specific technological resources that are relevant to K-8 mathematics education (e.g., Khan Academy, GeoGebra, Tinkercad, etc.). When referencing these resources, most PSTs did not describe how the resources might be used in a mathematics classroom but rather expressed some familiarity with the availability of the resources. Some PSTs (*n* = 7, 36.8%) discussed specific examples of pedagogical considerations that may be of interest when using technology during mathematics instruction. Pedagogical considerations mentioned by PSTs were fairly diverse, including topics such as allowing students to practice working with new concepts, establishing regulations and expectations, and differentiating instruction for different learning styles. Allowing students to play mathematical games was discussed by several PSTs (*n* = 5, 26.3%). While PSTs stressed the importance of ensuring that these games are centered on mathematics, no specific websites or games were mentioned in this regard. The final theme—knowledge of different devices that can be utilized for technology integration, such as Chromebooks and SMART Boards—was highlighted in the responses of a few PSTs (*n* = 4, 21.1%). Similar to the findings in regard to specific technological resources, PSTs' responses showed a familiarity with the availability of these devices rather than highlighting methods in which these devices can be used in the mathematics classroom.

Table 4

Emergent Coding: PSTs' Knowledge of Technology Integration

Theme	*n*	%	PSTs' Responses
Lack of knowledge	7	36.8%	• I don't know much about the different tools available through technology about math related apps, websites, etc. • In terms of math education, not a lot • I don't know a whole lot
Pedagogical considerations	7	36.8%	• Should be used to practice concepts, not explain new content • Regulations and expectations in the classroom where you use it • Can help with differentiation for students who learn in different ways
Specific technological resources	7	36.8%	• Khan Academy for math videos • GeoGebra, Tinkercad • Google Classroom
Mathematical games	5	26.3%	• Learning games that involve math concepts/strategies • Math-based computer games
Specific technological devices	4	21.1%	• Chromebooks • SMART Boards, calculators, and document cameras

Questions/Concerns Regarding Technology Integration

To investigate the second research question, PSTs' responses (n = 18) to P2 were analyzed. PSTs' responses were coded using the *a priori* codebooks of both the PICRAT and SAMR models as well as emergent coding to identify themes in order to uncover PSTs' questions/concerns about technology integration. Several PSTs' responses did not include enough information to be confidently coded by the researchers in alignment with the *a priori* codebooks, as ten responses (55.6%) did not receive a code regarding the PICRAT model and one response (5.6%) did not receive a code regarding the SAMR model. Additionally, one PST (5.6%) reported "I don't have any [questions/concerns] at this time" and was not coded during either the *a priori* or emergent coding processes.

Coding PSTs' responses in alignment with the PICRAT model was challenging on P2 as about half of the PSTs (n = 10, 55.6%) only discussed technology integration from the perspective of the teachers—excluding information about students. However, for PSTs' responses (n = 8, 44.4%) that included student information, all of the PSTs presented questions/concerns aligned with IA. PSTs highlighted students' interactive relationship to technology when expressing questions/concerns in regard to properly utilizing and overseeing the use of mathematical games in the classroom. Additionally, PSTs had questions/concerns related to: (a) determining whether games contain enriching mathematics content that would benefit students' learning outcomes and (b) ensuring that students stay on-task while playing mathematical games. All of the PSTs that did not pose questions/concerns related to students' relationship to technology discussed topics aligned with the replacement level of the RAT portion of the PICRAT model (n = 9, 50.0%). These PSTs often reported questions/concerns regarding the appropriate use of technology in the classroom (i.e., frequency/timing of technology integration) but did not express questions/concerns related to ways in which technology use might amplify either teachers' pedagogical practices or students' learning outcomes. Frequencies and examples of responses from PSTs that align with each level of the PICRAT model are displayed in Table 5.

Table 5

PICRAT Coding: PSTs' Technology Integration Questions and Concerns

Level	*n*	%	PSTs' Responses
Interactive, Amplification (IA)	8	44.4%	• Figuring out the interactives, games worth what the students will get out of it • Kids getting off track and doing things they aren't supposed to • My biggest concern would be students not staying on task or playing different apps or games than what was asked of them
Replacement	9	50.0%	• One of my biggest concerns is moving toward using only strictly technology in the classroom rather than paper/pencil and having students looking at a screen all day • When is the right time to use it? Could it become too much for younger students to handle? • How often should we use technology with math?

Table 6

SAMR Coding: PSTs' Technology Integration Questions and Concerns

Level	*n*	%	PSTs' Responses
Substitution	9	50%	• One of my biggest concerns is moving toward using only strictly technology in the classroom rather than paper/pencil and having students looking at a screen all day • When is the right time to use it? Could it become too much for younger students to handle? • How often should we use technology with math?
Augmentation	8	50%	• Figuring out the interactives, games worth what the students will get out of it • Kids getting off track and doing things they aren't supposed to • My biggest concern would be students not staying on task or playing different apps or games than what was asked of them

Similarly, all of PSTs' questions/concerns were coded as either substitution (n = 9, 50.0%) or augmentation (n = 8, 44.4%) when aligned with the SAMR model. PSTs' responses coded as substitution lacked questions/concerns related to technology use that provides a functional improvement to instruction and instead, primarily inquired about the frequency/timing of technology integration. Responses coded as augmentation contained questions/concerns about the use of technology (i.e., mathematical games) in the classroom in which a functional improvement to instruction was evident. No PSTs' responses were coded as either modification or redefinition on P2. Frequencies and examples of responses from PSTs that align with each level of the SAMR model are displayed in Table 6.

Emergent coding produced four primary questions about and/or concerns with technology integration in K-8 mathematics: (a) understanding when and how technology should be integrated, (b) strategies for keeping the focus on mathematics learning, (c) students' safety, and (d) students' misuse of technology. Frequencies and examples of PSTs' responses in relation to each theme are displayed in Table 7. One of PSTs' primary concerns regarding technology integration in mathematics relates to the appropriate integration of technology, as one third of PSTs (n = 6, 33.3%) asked how frequently technology ought to be utilized and for which purposes. Some PSTs (n = 6, 33.3%) posed questions regarding how technology can be implemented in a way in which the focus on mathematics learning is not compromised. Many of these comments were made in relation to the use of games in the mathematics classroom, as PSTs noted that some games lack significant mathematics content. Concerns associated with student's safety while using technological resources were expressed by several PSTs (n = 5, 27.8%), including topics such as inappropriate advertisements, the challenge of simultaneously monitoring all students' activities while using the internet, and the potential risk of increased screen time. The final theme, the misuse of technology, was highlighted by several PSTs (n = 5, 27.8%) when discussing topics such as students being off-task, not challenging themselves, or playing non-mathematics-related games.

Table 7

Emergent Coding: PSTs' Technology Integration Questions and Concerns

Theme	*n*	%	PSTs' Responses
When/how to integrate technology	6	33.3%	• How often should we use technology with math (daily, weekly, etc.)? • How do you balance lecture with technological involvement? • Should it be more practice-based, or testing only?
Focus on mathematics	6	33.3%	• Some websites have games that are not math-related • I think it's important to check the games that the students are playing for appropriateness and its math content
Safety	5	27.8%	• Making sure it can be safe for students • Ads pop up on games that students may click on • How do you oversee the use of Google? • A concern I have about using technology in the classroom is increasing students' screen time and the side effect of that
Misuse of technology	5	27.8%	• Kids getting off track and doing things they aren't supposed to • My biggest concern would be students not staying on task or playing different apps or games than what was asked of them

Anticipated Technology Integration Practices

PSTs' responses to P3 (n = 17) and P6 (n = 19) provided insight in regard to the third research question. PSTs' responses to each prompt were coded using the *a priori* codebooks of both the PICRAT and SAMR models as well as emergent coding to identify themes in order to assess PSTs' anticipated technology integration practices. Several PSTs' responses did not include enough information to be confidently coded by the researchers in alignment with the PICRAT model, as twelve responses (70.6%) on P3 and seven responses (36.8%) on P6 did not receive a code.

Likely due to the phrasing of P3, aligning PSTs' responses with the PICRAT model was difficult since the vast majority did not present responses that discussed students' relationship to technology. However, when aligning responses with the RAT portion of the PICRAT model, most PSTs' responses (n = 12, 70.6%) aligned with the amplification level, a little less than half (n = 7, 41.2%) aligned with the replacement level, and one (5.9%) aligned with the transformation level. In responses coded as amplification, PSTs often discussed using technology in order to enhance the lesson in some way, such as enabling differentiated instruction, increasing students' engagement, or benefiting students' learning. Responses coded as replacement contained PSTs' anticipated frequency of technology integration in their future classrooms but did not address how technology use might amplify either teachers' pedagogical practices or students' learning outcomes. The response of one PST was coded as transformation due to their discussion of how technology use in the classroom can provide students with an exploratory, student-centered learning environment. Frequencies and examples of responses from PSTs that align with each level of the PICRAT model are displayed in Table 8.

Table 8

PICRAT Coding: PSTs' Anticipated Technology Integration Frequency

Level	*n*	%	PSTs' Responses
Replacement	7	41.2%	• As a supplement to traditional problems • I plan on using educational technology in my math lessons as often as they apply
Amplification	12	70.6%	• Using technology to help them practice will be very beneficial • I have experience first-hand how useful technology can be in the math classroom, especially for differentiated instruction
Transformation	1	5.9%	• I think using technology while teaching math can be very engaging and a really key way for students to control their learning and dive into new ideas on their own

When coded in alignment with the SAMR model, most PSTs' responses (n = 11, 64.7%) were coded as augmentation, a little less than half (n = 7, 41.2%) were coded as replacement, and just three (17.6%) were coded as modification. When reporting their intended frequency of technology integration, the majority of PSTs provided responses in which they discussed how technology use would improve instruction in some way (i.e., pedagogical practices or students' outcomes)—aligning with the augmentation level of the SAMR model. Some PSTs' excluded information in regard to how technology use might improve instruction and rather discussed their intentions for technology integration in a way that suggested the technological resource would act as a substitute. A few PSTs' responses were coded as modification since their descriptions of the learning environment promoted by the use of technology implied a significant redesign of the mathematical task. Frequencies and examples of responses from PSTs that align with each level of the SAMR model are displayed in Table 9.

Table 9

SAMR Coding: PSTs' Anticipated Technology Integration Frequency

Level	*n*	%	PSTs' Responses
Substitution	7	41.2%	• As a supplement to traditional problems • I plan on using educational technology in my math lessons as often as they apply
Augmentation	11	64.7%	• Using technology to help them practice will be very beneficial • I have experience first-hand how useful technology can be in the math classroom, especially for differentiated instruction
Modification	3	17.6%	• I think using technology while teaching math can be very engaging and a really key way for students to control their learning and dive into new ideas on their own • There are many great resources out there that can enrich your teaching in math and enrich the learning of others

Table 10

Emergent Coding: PSTs' Anticipated Technology Integration Frequency

Theme	*n*	%	PSTs' Responses
Very frequently	3	17.6%	• I plan on using educational technology in my classroom very frequently • Daily, as long as it supports my lessons and content being taught
Somewhat frequently	7	41.2%	• I think I would use math technology fairly frequently • I would hope at least several times a week • I plan/hope to use it pretty frequently
Occasionally	4	23.5%	• I will probably use educational technology in the math classroom for some examples when teaching • Probably an average amount unless I was absolutely certain about some kind of technology to integrate
Somewhat infrequently	1	5.9%	• I think I would use technology less within the classroom when it comes to math
Very infrequently	2	11.8%	• At this point I feel like I would not use educational technology in the math classroom

After examining PSTs' (n = 17) responses on P3, the researchers found evidence of five different levels of anticipated use as displayed in Table 10. The majority of PSTs who responded to P3 stated that they planned to integrate technology into their mathematics lessons relatively frequently in their future classrooms. A few PSTs (n = 3, 17.6%) suggested they would integrate technology very frequently (e.g., daily); a little less than half of PSTs (n = 7, 41.2%) noted somewhat frequently (e.g., weekly, several times per week, fairly frequently); several PSTs (n = 4, 23.5%)

proposed an occasional use of technology (e.g., for some examples, an average amount); one PST (5.9%) reported somewhat infrequently (e.g., would use technology less); and two PSTs (11.8%) supported a very infrequent integration of technology (e.g., would not use educational technology).

Coding of PSTs' responses to P6 only produced two codes when aligned with the PICRAT model, IA (*n* = 12, 63.2%) and IR (*n* = 1, 5.3%), with nearly all responses coded as IA. Students' interactive relationship to technology was highlighted by many PSTs when discussing how virtual manipulatives and mathematical games can be used in the classroom to explain and practice mathematics concepts. PSTs' responses highlighted that students' interactive use of technology may amplify instruction in several ways, such as increasing students' engagement, enhancing students' learning outcomes, and allowing the teacher to easily differentiate instruction. Just one PST's response was coded as IR, in which the PST discussed students' use of an interactive whiteboard (i.e., SMART Board) where the interactive whiteboard acted as a substitute to a traditional whiteboard/chalkboard that is not interactive. Frequencies and examples of responses from PSTs that align with each level of the PICRAT model are displayed in Table 11.

Table 11

PICRAT Coding: PSTs' Perspectives on the Most Practical Application of Technology Integration

Level	*n*	%	PSTs' Responses
Interactive, Replacement (IR)	1	5.3%	• Projecting virtual base 10 blocks on a projector in order to efficiently give students instruction on how to use them or doing a whole class activity involving a virtual number line
Interactive, Amplification (IA)	12	63.2%	• Technology can be a wonderful way for students to practice independently and receive feedback on their responses in a timely manner • Incorporating games…as a reward for good behavior • Assessments where questions can vary harder and easier would be a good use of technology in a math classroom • The use of virtual manipulatives to foster students' conceptual understanding and provide practice with mathematical procedures

Similarly, the vast majority of PSTs' responses were coded as augmentation (*n* = 16, 84.2%) when aligned with the SAMR model. PSTs' discussed how the use of virtual manipulatives and mathematical games in the classroom can improve the lesson in some way (i.e., improving efficiency, increasing students' engagement, and providing students with instant feedback). Two PSTs' responses (10.5%) were coded as substitution since they discussed the use of interactive whiteboards without addressing potential improvements to instruction. Lastly, two PSTs' responses (10.5%) were coded as modification due to their discussions of using various technological resources to differentiate instruction in accordance with the educational needs of each individual student, which indicates a significant redesign of mathematical tasks due to the use of technology. On P6, no PSTs' responses were coded as redefinition. Frequencies and examples of responses from PSTs that align with each level of the SAMR model are displayed in Table 12.

Table 12

SAMR Coding: PSTs' Perspectives on the Most Practical Application of Technology Integration

Level	*n*	%	PSTs' Responses
Substitution	2	10.5%	• Projecting virtual base 10 blocks on a projector in order to efficiently give students instruction on how to use them or doing a whole class activity involving a virtual number line
Augmentation	16	84.2%	• Technology can be a wonderful way for students to practice independently and receive feedback on their responses in a timely manner • Assessments where questions can vary harder and easier would be a good use of technology in a math classroom • The use of virtual manipulatives to foster students' conceptual understanding and provide practice with mathematical procedures
Modification	2	10.5%	• Technology gives you the opportunity to distribute the correct content matter to the correct level of each student

Table 13

Emergent Coding: PSTs' Perspectives on the Most Practical Application of Technology Integration

Theme	*n*	%	PSTs' Responses
Student practice	6	31.6%	• I think the most practical application of technology in K-8 math is when students have learned the concepts and will them practice applying what they know • I think the most practical application of technology is for student practice
Assessment	6	31.6%	• Assessments where questions can vary harder and easier would be a good use of technology in a math classroom • Widely used in assessments
Differentiation	6	31.6%	• Technology gives you the opportunity to distribute the correct content matter to the correct level of each student • When looking at the many different learning styles it is a great idea to incorporate many different platforms of learning • Gives students who are visual and kinetic learners a new way to see the information
Using virtual manipulatives	5	26.3%	• One of the best uses of technology might be the use of virtual manipulatives to foster students' conceptual understanding and provide practice with mathematical procedures • Virtual manipulatives have the advantage over traditional [physical] manipulatives by decreasing clean up time, distractions, and transitions in the lesson

The investigation of the application of technology integration in mathematics which K-8 PSTs perceived to be the most practical (P6) produced four themes: (a) student practice of specific skills, (b) assessment, (c) differentiation, and (d) using virtual manipulatives. Frequencies and examples of PSTs' (n = 19) responses that align with each theme are displayed in Table 13. About one third of the PSTs (n = 6, 31.6%) explained how students can use technological resources to solidify their understanding of content immediately following teacher-led instruction. In this regard, PSTs often discussed having students practice the application of newly learned knowledge by playing mathematical games that might improve either procedural or conceptual understanding. Other PSTs (n = 6, 31.6%) reported that assessment was the most practical application of technology integration, though none provided specific strategies in which technological resources might be used to assess students' understanding. The relationship between differentiation and technology integration was noted by some PSTs (*n* = 6, 31.6%), most frequently discussing resources that allow students to progress through a lesson at different rates or resources that address the needs of various learning styles. The final theme—using virtual manipulatives—was discussed by several PSTs (*n* = 5, 26.3%) in a variety of contexts. PSTs noted that students may benefit from using virtual manipulatives as this use may promote the development of conceptual understanding. Additionally, PSTs noted that virtual manipulatives may offer pedagogical improvements, such as by reducing the time that would have otherwise been spent handing out or gathering physical/concrete materials.

Impact of Technological Resources on Mathematics Instruction

Table 14

PICRAT Coding: Impact of Technological Resources on Mathematics Instruction (P4)

Level	*n*	%	PSTs' Responses
Passive, Amplification (PA)	2	11.1%	• To help students understand the connection of decimals and fractions they could start by watching a video that has a pizza and converts the slices of pizza into fractions of pizza and then decimals as well • They can hop onto the website and watch educational videos posted by math professionals to help them learn in a different way
Interactive, Amplification (IA)	12	66.7%	• The resource I used was using base ten blocks to create numbers between 0 and 99 from the GeoGebra website…this tool would allow students to visualize number grouped in place values • [The virtual pan balance] allows students to use different equations and shows whether they are equal, greater than, or less than. This could also easily show the commutative and associative property of multiplication. Ideally this would be used for a short time after teaching the concepts so students could see for themselves how these properties work.
Creative, Transformation (CT)	2	11.1%	• Kids will arrange physical tiles, dots, and digits to make numbers and complete levels…lots of manipulatives and objects to use in front of the OSMO camera • I will be using GeoGebra in my future classroom because it will allow my students to manipulate math graphs, equations, etc. while seeing the affect that manipulation creates which is a powerful resource

The fourth research question was examined with PSTs' responses to P4 (*n* = 18) and P5 (*n* = 19). PSTs' responses were coded using the *a priori* codebooks of both the PICRAT and SAMR models in order to assess the impact of the proposed use of technology on mathematics instruction. Emergent coding was not utilized to explore this research question since the PICRAT and SAMR models were specifically designed for this context. Due to the similarity of P4 and P5 (e.g., both prompts ask PSTs to describe the use of educational technology in a K-8 mathematics classroom), the results of coding PSTs' responses to these prompts are presented concurrently rather than independently.

Table 15

PICRAT Coding: Impact of Technological Resources on Mathematics Instruction (P5)

Level	*n*	%	PSTs' Responses
Passive, Amplification (PA)	1	5.3%	• [Khan Academy] would help to benefit a lesson by giving students different outlets to learn the material…and watch educational videos
Interactive, Amplification (IA)	15	78.9%	• Splash Math…allows you to keep track of your students' progress and shows students a map of their progress and where they are headed next. I also like it because it is very interactive and the more the student gets right the harder the questions get so it really pushes them • Desmos has created their activities in such a way that students are provided feedback along with the opportunity to collaborate on activities that prove as a useful formative assessment to monitor student progress
Creative, Transformation (CT)	2	10.5%	• OSMO…is hands on and has many ways to change and modify what a student might be working on. I would be able to record student answers and scores as they work with OSMO. This tool also comes with manipulatives and you could assess by looking in front of the tablet to physically see their work with various tasks • GeoGebra allows students to create and manipulate diagrams, graphs, shapes etc. Using GeoGebra in the classroom can allow students to explore mathematical concepts in a safe, engaging setting

On both P4 and P5, the vast majority of PSTs' responses (P4: *n* = 12, 66.7%; P5: *n* = 15, 78.9%) were coded as IA when aligned with the PICRAT model. To this end, many PSTs described activities in which students' interactive use of mathematical games and virtual versions of mathematics tools (i.e., base-ten blocks, ten frames, balances, protractors, and number lines) were highlighted. PSTs noted that this use of technology amplifies instruction by providing students with instant feedback, increasing students' engagement, and allowing students to visualize mathematics concepts. In other responses coded as IA, PSTs described students' use of various online programs (i.e., BrainPOP, SplashLearn, and Nearpod) that guide students through interactive mathematics content. In responses that discussed these resources, PSTs primarily mentioned how these resources amplify instruction from the perspective of the teacher (i.e., improving efficiency, integrating assessments, and providing teachers with progress reports). Few PSTs (P4: *n* = 2, 11.1%; P5: *n* = 1, 5.3%) discussed similar resources (i.e., Khan Academy and Dreambox Learning) that amplify instruction. However, these responses were coded as PA as the PSTs primarily discussed students' passive use of this technology (i.e., watching educational videos). Lastly, a few PSTs (P4: *n* = 2, 11.1%; P5: *n* = 2, 10.5%) described uses of technology that aligned with CT. Students' creative relationship to technology was highlighted by students' use of technological resources (i.e., GeoGebra and Osmo) to create and manipulate virtual representations of mathematics concepts. These instances of technology integration have a transformative impact on instruction, as the described activities (i.e., using GeoGebra to create and manipulate graphs/equations and using Osmo to work with physical and virtual tools simultaneously) would be impractical or inconceivable without the use of technology. On P4 and P5, no PSTs' responses were coded as any of the other PICRAT levels by both coders. Frequencies and examples of responses from PSTs that align with each level of the PICRAT model are displayed in Table 14 (P4) and Table 15 (P5).

Figure 3

Osmo's Tangram Game

Note. (Osmo, 2022)

When coding in alignment with the SAMR model, the vast majority of PSTs' responses to P4 and P5 were coded as augmentation (P4: n = 10, 55.6%; P5: n = 14, 73.7%). In these responses, PSTs described uses of technology (i.e., virtual tools and mathematical games) that improve instruction for both teachers and students. A few PSTs' responses (P4: n = 3, 16.7%; P5: n = 2, 10.5%) were coded as substitution as they discussed the use of educational videos as a substitute for traditional instruction without explicitly describing improvements to instruction. Several PSTs' responses (P4: n = 4, 22.2%; P5: n = 2, 10.5%) suggested a significant task redesign and were coded as modification, as their description highlighted students' use of virtual manipulatives to create and manipulate graphs and equations. Lastly, just one PST's response (P4: n = 1, 5.6%; P5: n = 1, 5.3%) was coded as redefinition, as the use of technology enabled a previously inconceivable mathematics task. This response highlighted students' use of Osmo—the red-colored device on the top of the tablet in Figure 3—to examine, compose, and decompose various shapes and figures using both physical and virtual modalities simultaneously. Frequencies and examples of responses from PSTs that align with each level of the SAMR model are displayed in Table 16 (P4) and Table 17 (P5).

Table 16

SAMR Coding: Impact of Technological Resources on Mathematics Instruction (P4)

Level	*n*	%	PSTs' Responses
Substitution	3	16.7%	• To help students understand the connection of decimals and fractions they could start by watching a video that has a pizza and converts the slices of pizza into fractions of pizza and then decimals as well
Augmentation	10	55.6%	• The resource I used was using base ten blocks to create numbers between 0 and 99 from the GeoGebra website…this tool would allow students to visualize number grouped in place values • [The virtual pan balance] allows students to use different equations and shows whether they are equal, greater than, or less than. This could also easily show the commutative and associative property of multiplication. Ideally this would be used for a short time after teaching the concepts so students could see for themselves how these properties work.
Modification	4	22.2%	• I will be using GeoGebra in my future classroom because it will allow my students to manipulate math graphs, equations, etc. while seeing the affect that manipulation creates which is a powerful resource
Redefinition	1	5.6%	• Kids will arrange physical tiles, dots, and digits to make numbers and complete levels…lots of manipulatives and objects to use in front of the OSMO camera

Table 17

SAMR Coding: Impact of Technological Resources on Mathematics Instruction (P5)

Level	*n*	%	PSTs' Responses
Substitution	2	10.5%	• [Khan Academy] would help to benefit a lesson by giving students different outlets to learn the material…and watch educational videos
Augmentation	14	73.7%	• Splash Math…allows you to keep track of your students' progress and shows students a map of their progress and where they are headed next. I also like it because it is very interactive and the more the student gets right the harder the questions get so it really pushes them • Desmos has created their activities in such a way that students are provided feedback along with the opportunity to collaborate on activities that prove as a useful formative assessment to monitor student progress
Modification	2	10.5%	• GeoGebra allows students to create and manipulate diagrams, graphs, shapes etc. Using GeoGebra in the classroom can allow students to explore mathematical concepts in a safe, engaging setting
Redefinition	1	5.3%	• OSMO…is hands on and has many ways to change and modify what a student might be working on. I would be able to record student answers and scores as they work with OSMO. This tool also comes with manipulatives and you could assess by looking in front of the tablet to physically see their work with various tasks

Discussions

Methods of Achieving Validity and Reliability

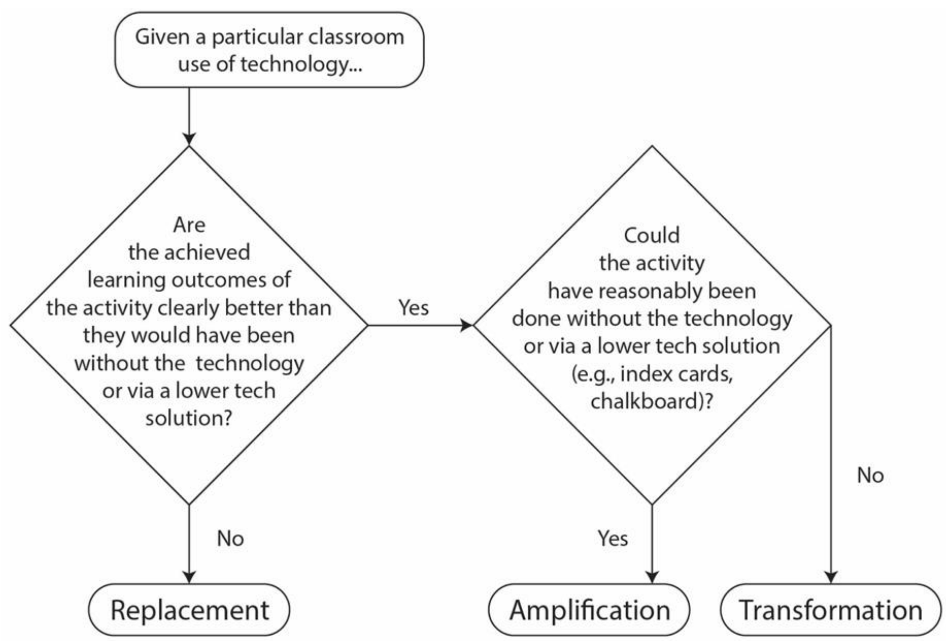
Based on the recommendation of Creswell and Poth (2017), several methods were utilized in order to increase the validity of this qualitative study. We presented rich descriptions of our research process to increase dependability—enabling others to follow and critique our decisions. Additionally, we utilized two *a priori* codebooks (PICRAT and

SAMR) to confirm our coding procedures and analyzed multiple data sources (i.e., multiple prompts at multiple points in time) to confirm our findings. Appropriate transferability is established with our clear descriptions of the site, population, and sample of this study. To increase the authenticity of this study, we have positioned ourselves within the context in which this study occurred. Lastly, employing an approach that utilized multiple coders and authors increased the reliability of our findings.

Comparison of the PICRAT and SAMR Models

Figure 4

PICRAT Flowchart for the RAT



Note. (Kimmons et al., 2020)

Findings in regard to the comparison of the PICRAT and SAMR models highlight the reliability and utility of the PICRAT model. Though the PICRAT model contains nine distinct levels and the SAMR model contains four, the mean weighted IRR for both models were nearly identical (80.9% and 80.0%) when applied by the coders in this study. Additionally, when comparing the three-level RAT portion of the PICRAT model and the SAMR model—which both categorize the impact of a technological resource on instruction—the RAT attained a greater mean weighted IRR (87.3% versus 80.0%). This is likely partially due to the RAT having fewer levels but is potentially also attributable to the rich description of the distinctions between levels presented by Kimmons et al. (2020), as well as the flowchart used to supplement these descriptions as shown in Figure 4. Furthermore, the researchers agree with Kimmons and colleagues' critique of the SAMR model in which they state that the SAMR model is somewhat challenging to apply due to the unclear distinctions between levels (e.g., augmentation versus modification). The RAT, on the other hand, contains well-defined distinctions between levels and includes an easily-understood flowchart.

As previously suggested, the SAMR and PICRAT models provide distinct but complementary perspectives regarding technology integration. While the SAMR model captures an arguably more in-depth analysis of technology's impact on instruction, the PICRAT model highlights students' relationship with the technology. In this study, the use of the PICRAT model provided a more nuanced analysis of technology use since technology integration from the perspective of the student was included. That being said, the PICRAT model may be more challenging to apply as a theoretical lens in some contexts since accurate categorizations require additional insight and information—namely students' relationship with the technological resource.

PSTs' Knowledge of Technology Integration

Findings of the emergent coding in regard to Q1 (What knowledge of technology integration in mathematics do K-8 PSTs possess as viewed through the lens of both the SAMR and PICRAT models?) suggest that PSTs hold somewhat limited knowledge of technology integration in mathematics as 36.8% of PSTs explicitly reported this lack of knowledge of and/or experience with technology integration. This finding is slightly concerning, as the participants of this study are enrolled in either their final or penultimate year in the elementary education program. However, a fair number of PSTs did demonstrate some knowledge of technology integration as they discussed various mathematical games (26.3%), specific technological devices (21.1%) and resources (36.8%), and numerous pedagogical considerations that are relevant to the use of technology (36.8%). Overall, PSTs seem most familiar with the use of students' use of mathematical games in the classroom as this topic was frequently discussed in PSTs' responses to all six prompts. More so, PSTs appear to be most knowledgeable of uses of technology that are categorized as either IA or IR when examined with the PICRAT model and either augmentation or substitution when examined with the SAMR model. Prior research has highlighted similar findings regarding PSTs' knowledge of technology integration. For example, Wachira et al.'s (2008) qualitative examination found that middle school mathematics PSTs "showed a limited understanding of technology as a powerful tool to help students gain a deeper understanding and appreciation of mathematical concepts and skills" and "did not provide specific ways on how technology could be used to promote learning" (p. 302).

PSTs' Questions/Concerns Regarding Technology Integration

The themes identified during the analysis of Q2 (What questions/concerns do K-8 PSTs have regarding technology integration in mathematics as viewed through the lens of both the SAMR and PICRAT models?) suggest that PSTs have questions/concerns with how to appropriately facilitate and implement technology integration. Facilitation concerns included students' misuse of technology (27.8%) and internet safety (27.8%), while questions of best practices for implementation included keeping students focused on mathematics (33.3%) and knowing when and how to integrate technology (33.3%). These findings align with the feelings of unpreparedness experienced by PSTs as described by Tondeur et al. (2012) and PSTs' lack of confidence in relation to integrating technology as noted by Crompton (2015).

PSTs' Anticipated Technology Integration Practices

Responses related to Q3 (What are K-8 PSTs' anticipated technology integration practices for their future mathematics classrooms as viewed through the lens of both the SAMR and PICRAT models?) show that PSTs are generally optimistic in terms of technology integration in their future classrooms as many reported intentions to integrate technology on a daily (17.6%) or weekly basis (41.2%). However, few detailed examples were provided when PSTs described what they perceived to be the most practical application of technology integration in mathematics. These findings align with those of Cullen and Greene (2011) who found that 74% of kindergarten through twelfth grade PSTs enrolled in a technology integration course (n = 114) were either *very likely* or *likely* to use technology in the classroom when surveyed at the end of the course, yet "struggled to design meaningful technology integration activities" (p. 29).

PSTs' Proposed Uses of Technology in K-8 Mathematics

Findings in regard to Q4 (For K-8 PSTs' proposed uses of technology in mathematics, how would the technological resource impact mathematics instruction as viewed through the lens of both the SAMR and PICRAT models?) are highlighted by PSTs' tendency to describe instances of technology integration that align with the interactive, amplification level (IA; P4: 66.7%, P5: 78.9%) of the PICRAT model and the augmentation level (P4: 55.5%, P5: 73.7%) of the SAMR model. Mathematical games and virtual mathematics tools were frequently utilized in these responses. Additionally, very few PSTs proposed uses of technology that were coded as PICRAT/SAMR levels that indicate a significant impact on mathematics instruction (e.g., CA, IT, CT, modification, and redefinition). In the literature, few studies examined activities designed by K-8 PSTs to assess their proposed uses of technology in mathematics through the lens of the SAMR or PICRAT models. However, the lack of responses that were coded as PICRAT/SAMR levels that indicate a significant impact on mathematics instruction aligns with prior studies' findings of PSTs' unpreparedness to meaningfully integrate technology into their future classrooms (Tondeur et al., 2012). Likely due to the recency of the PICRAT model, no studies have examined K-8 mathematics activities that utilize a technological resource designed by PSTs in accordance with the PICRAT model. Thus, this study provides an example of applying the PICRAT model to PSTs' classroom artifacts as well as describes PSTs' tendencies of integrating technology in K-8 mathematics in respect to the various levels of the PICRAT model—namely their intentions to have students interactively utilize mathematical games and virtual mathematics tools in a way that amplifies mathematics instruction.

Conclusion

Conclusions

Based on the findings of this study, more ought to be done to prepare K-8 PSTs to integrate technology into mathematics. At the postsecondary institution at which this study was conducted, PSTs complete a stand-alone technology integration course (i.e., Integrating Technology into Education)—with enrollment in the course recommended during PSTs' second year of undergraduate study. Thus, the sample in this study have possibly had little exposure to and practice with technology integration for the previous one-to-two academic years as the sample consisted of PSTs in their third and fourth years of study. In alignment with prior research (Brush et al., 2003; Zipke, 2018), the findings of this study suggest that a stand-alone technology integration course may not be sufficient in preparing K-8 PSTs to meaningfully integrate technology into mathematics.

Limitations

The primary limitation of this study relates to external validity, as this study examined a small convenience sample of PSTs at one postsecondary institution. Thus, findings may not be generalizable to PSTs enrolled in other postsecondary institutions or other groups of PSTs. An additional limitation related to external validity is the fact that data were gathered over a two-week period, so the findings represent a cross section of PSTs' perspectives that may not align with their perspectives during other time periods or over a longer duration of time. In regard to internal validity, contamination is a potential limitation of this study. PSTs were instructed to independently respond to the prompts utilized during data collection. However, there is always the possibility that students may work together outside of the classroom. The researchers did not observe any cases that suggested contamination in this study, but the potential for this threat to internal validity warrants recognition. Another limitation related to internal validity is the potential impact of the two-day lesson on PSTs' perspectives on technology integration in K-8 mathematics. The lesson was a necessary aspect of this study as it would be unethical to withhold information on technology integration from PSTs, but the authors feel the need to identify this as a potential limitation. It is worth noting that data were gathered two months prior to the onset of the COVID-19 pandemic, so current PSTs' perspectives on technology integration may differ from the findings of this study. Lastly, it is possible that the prompts could have been modified in a way such that PSTs' responses would have provided information more related to the PICRAT and SAMR models, which may have enhanced the *a priori* coding process and the fit between the prompts and the research questions of the study. Due to the potential misalignment between the prompts and research questions, the researchers urge caution when interpreting the findings, especially when trying to generalize the findings to other groups of PSTs within different contexts.

Implications for Future Research

Based on the reliability and utility of the PICRAT model, the researchers suggest this technology integration model be utilized when examining PSTs' technology integration perspectives and intentions. In this study, the PICRAT model attained a similar mean weighted IRR when compared to the SAMR model. Additionally, the PICRAT model provides valuable information regarding students' relationship to technology which is not specified when only utilizing the SAMR model. Lastly, after coding PSTs' responses with both the PICRAT and SAMR models, the researchers agreed with Kimmons and colleagues' (2020) critique of the SAMR model's ambiguous boundaries between levels. Thus, the researchers feel that utilizing the PICRAT model as a theoretical frame is beneficial in regard to reliability, utility, and ease of use and recommend utilizing the PICRAT model to guide future research on technology integration. However—based on the researchers challenges with coding in alignment with the PIC portion of the model due to lack of detail in PSTs' responses—it is recommended that data collection methods that emphasize students' use of technology are utilized in order to more precisely investigate questions related to PSTs' perspective on or anticipated practices for technology integration.

When discussing teacher education, Kimmons et al. (2020) recommended that PSTs and teachers use the PICRAT model to consider how "lower-level uses (e.g., digital flashcards or lecturing with an electronic slideshow) could be shifted to higher-level uses (e.g., problem-based learning video games or Skype video chats with experts)" (p. 190). Additionally, Austin and Kosko (2022) found that PSTs' are more likely to adopt technology integration practices for mathematics when they are explicitly modeled in their mathematics methods courses. Future research that examines the impact of embedding and modeling PICRAT-based technology integration experiences within mathematics methods courses—or all methods courses as suggested by Trainin et al. (2018)—may add to our understanding of K-8 PSTs' relationship with technology integration in mathematics and our knowledge of how to best prepare K-8 PSTs to meaningfully integrate technology into their future classrooms.

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