K-8 PRESERVICE TEACHERS' PREPAREDNESS FOR TECHNOLOGY INTEGRATION IN MATHEMATICS: EXAMINING PERSPECTIVES, ANTICIPATED PRACTICES, AND ABILITIES

by

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DEDICATION

This dissertation is dedicated to my wife, Kaitlyn. Thank you for always supporting me, loving me, and having fun with me.

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ABSTRACT

Research on the use of technological resources—such as virtual manipulatives and mathematical games—in kindergarten through eighth-grade mathematics has highlighted numerous benefits to students' achievement in and attitudes toward mathematics. However, studies have also highlighted preservice teachers' lack of preparedness to integrate technology into their future classrooms. Thus, the purpose of this dissertation is to examine kindergarten through eighth-grade preservice teachers' preparedness to integrate technology into mathematics by analyzing their perspectives on technology integration, their anticipated technology integration practices, and their technology integration abilities. In this three-manuscript dissertation, qualitative analyses employed a social constructivist paradigm and utilized an ethnographic approach to examine preservice teachers' preparedness to integrate technology. By using the PICRAT model as a guiding theoretical framework in each study, preservice teachers' perspectives and abilities were examined in relation to how their anticipated uses of technology would impact mathematics instruction in respect to both students' learning and teachers' pedagogical practices.

Findings showed that preservice teachers' tended to report a lack of knowledge in relation to technology integration and both ask questions and express concerns related to how to appropriately integrate technology into mathematics. Nevertheless, preservice teachers also reported an intent to integrate technology into their future classrooms at a relatively frequent basis. When examining preservice teachers' abilities to either evaluate an existing geometry activity or create a geometry activity that utilizes a technological resource, preservice teachers tended to evaluate or create activities that integrated technology in a way that both enabled interactive learning on behalf of the students and amplified teachers' pedagogical practices. Activities that used technological resources to either promote students' passive learning or replace teachers' practices were less frequent, and activities that used technology to either foster students' creative learning or transform teachers' practices were rare. Additionally, preservice teachers' activities tended to align with PICRAT levels that are associated with higher degrees of impact on mathematics instruction when preservice teachers evaluated activities rather than created activities. To conclude, implications for teacher education programs and areas of future research are presented and discussed.

CHAPTER ONE

INTRODUCTION

The purpose of this dissertation is to examine current kindergarten through eighth-grade (K-8) preservice teachers' (PSTs') preparedness to integrate technology into mathematics. To examine this topic, I organized this three-manuscript dissertation around the following primary research question: What are K-8 PSTs' perspectives on technology integration, anticipated practices for technology integration, and technology integration abilities in the context of mathematics? In this chapter, I present a brief review of the literature, establish the significance of the research topic, describe the guiding theoretical and conceptual frameworks, summarize the structure of this three-manuscript dissertation, and explicitly outline the relationship between the three manuscripts in respect to the overall purpose of this dissertation.

Brief Review of the Literature

The use of technological resources in K-8 mathematics has been associated with numerous benefits to students. However, research has also suggested that PSTs are generally not prepared to integrate technology into their future classrooms upon degree completion. In this brief review of the literature, I first highlight research findings related to the impact of technology use on students' mathematics achievement and attitudes toward mathematics and also summarize the literature regarding PSTs' preparedness to integrate technology into their future classrooms.

K-8 Students' Use of Technology in Mathematics

In the context of mathematics, technological resources commonly integrated into the classroom are virtual manipulatives and mathematical games. Virtual manipulatives have been defined as "an interactive, Web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge" (Moyer et al., 2002, p. 373). Websites and software packages allow students to explore various mathematical concepts through the use of virtual manipulatives, such as: (a) manipulating right triangles to investigate the Pythagorean Theorem, (b) creating and manipulating three-dimensional objects, (c) arranging tiles to investigate quadratic expressions, and (d) practicing arithmetic operations with base-ten blocks (Moyer et al., 2002). Moyer and colleagues highlighted several advantageous properties of virtual manipulatives, including free access for schools, home availability for students and parents, and less time spent distributing and gathering materials during lessons. The numerous applications and advantages of virtual manipulatives make them a very practical tool in the mathematics classroom. Much of the research on the use of games in education pertains to the implementation of game-based learning, which has been defined as a type of digital game play with defined learning outcomes (Plass et al., 2015). Often—and perhaps ideally—these games have been designed in a way that is "personally meaningful, experiential, social, and epistemological all at the same time" and deeply grounded in age-appropriate learning theories (Shaffer et al., 2005, p. 105). When practicing game-based learning in mathematics, students are able to study traditional mathematics content in an engaging and enjoyable environment.

Impact of Technology Use on Achievement in Mathematics.

Research on the use of virtual manipulatives and mathematical games in elementary school settings has indicated a

significant positive effect on students' mathematics achievement when compared to either direct instruction or the use of physical manipulatives. For instance, students who used virtual manipulatives experienced significant improvements in conceptual knowledge regarding fractions (Reimer & Moyer, 2005) and various geometry concepts (Suh & Moyer, 2007). These findings may be especially important to the field of mathematics education research as these concepts are applicable to a wide variety of situations outside of the classroom setting. Suh and Moyer identified unique features of virtual manipulatives that promoted student thinking, such as "(a) explicit linking of visual and symbolic modes; (b) guided step-by-step support in algorithmic processes; and (c) immediate feedback and self-checking system" (p. 165). Additionally, studies have shown that students who used mathematical games in the classroom experienced significantly higher achievement in mathematics, such as earning higher scores on assessments of multiplication skills (Kiger et al., 2012), adaptive number knowledge, and arithmetic fluency (Brezovszky et al., 2019). Overall, the literature shows that elementary school students greatly benefit from the use of technology in the mathematics classroom.

Studies have shown that the use of virtual manipulatives seems to have less of an effect on the mathematics achievement of middle school students when contrasted with elementary school students, though findings are still promising. For example, some studies have found that the use of virtual manipulatives are just as effective as the use of physical manipulatives (Sen et al., 2017; Yuan et al. 2010). However, Ha and Fang (2018) found that the simultaneous use of virtual and physical manipulatives produced a statistically significant increase in achievement regarding middle school students' spatial visualization abilities. Additionally, students generally preferred to use both forms of manipulatives simultaneously rather than using either form

individually, as "PMs [physical manipulatives] provided students with a sense of touch and connectedness to the learning materials, while working on the computer gave students secure feeling as the computer always quickly provided the correct rotation angles and clear visualization" (Ha & Fang, 2018, p. 1104). The use of mathematical games has been found to be associated with achievement gains as well. For example, middle school students who used mathematical games when learning about pre-algebra concepts achieved significantly higher post-test scores when compared to students who did not use games (Brezovszky et al., 2019). While the research is less clear at the middle school level, several benefits to students are highlighted in the literature.

Lastly, the use of virtual manipulatives and mathematical games have been found to be especially beneficial to the mathematics achievement of K-8 students with disabilities. In regard to the use of virtual manipulatives, elementary school students with autism spectrum disorders have demonstrated an increased rate of learning (Root et al., 2017), greater accuracy, and faster independence (Bouck et al., 2014) when compared to students who used physical manipulatives. More so, students in these studies reported that they preferred using virtual manipulatives rather than physical manipulatives. Studies examining middle school students with disabilities have found that—while accuracy and task completion time remained constant—students were more independent when using virtual manipulatives when compared to physical manipulatives (Bouck et al., 2017; Bouck, Shurr, et al., 2018). Additionally, research has found that middle school students with disabilities often preferred virtual manipulatives to physical manipulatives (Bouck et al., 2017). Several studies have uncovered the benefits of the use of mathematical games for students with disabilities. For example, studies that examined students' fraction knowledge have

found that the use of mathematical games produced significantly higher increases in achievement as well as retention of knowledge when compared to students who received traditional instruction (Brown et al., 2011; Simsek, 2016). Not only do students with disabilities demonstrate higher achievement with the use of virtual manipulatives and mathematical games, but they are also given the opportunity to engage with mathematics content in an enjoyable, independence-promoting learning environment.

Impact of Technology Use on Attitudes Toward Mathematics. The literature has highlighted the beneficial impact of virtual manipulatives and mathematical games on several constructs related to students' attitudes toward mathematics. Overall, many studies have found that virtual manipulative use increased positive attitudes toward mathematics for elementary school students (Lee & Chen, 2015). Students have reported that virtual manipulatives help them learn since they received immediate feedback, were easy to use and faster than traditional methods, and enhanced enjoyment (Reimer & Moyer, 2005). Additionally, in Steen et al. (2006), a teacher reported that students were more on-task and seemed to enjoy the activities when using virtual manipulatives. In regard to mathematical games, studies have shown numerous benefits to elementary school students, such as increased enjoyment, engagement, motivation, and overall attitudes toward mathematics (Shin et al., 2012; Watson-Huggins & Trotman, 2019; White & McCoy, 2019). In general, both virtual manipulatives and mathematical games seem to provide elementary school students with satisfying learning environments that enhance their attitudes toward learning mathematics.

Similarly, attitudes toward mathematics have been found to be positively correlated with the use of virtual manipulatives for middle school students. Students who used virtual

manipulatives in class have reported higher levels of motivation, more positive attitudes (Sen et al., 2017), increased confidence, and increased excitement (Yuan et al., 2010). Additionally, students have reported that virtual manipulative use was intrinsically rewarding and increased students' feelings of competency in mathematics (McLeod et al., 2013). Mathematical games have also been shown to increase middle school students' attitudes toward mathematics, as studies have identified increases in enjoyment, self-confidence, motivation, and one's value of mathematics due to the use of mathematical games in the classroom (Fabian et al., 2018; Mavridis et al., 2017; Siew et al., 2016). Thus, the use of both virtual manipulatives and mathematical games seem to positively impact middle school students' overall attitudes toward mathematics as well.

Preservice Teachers' Preparedness to Integrate Technology

Due to the aforementioned benefits of technology integration on students' mathematics achievement and attitudes, it is crucial that PSTs are prepared to integrate technology into their future mathematics classrooms upon degree completion—especially considering that 92% of administrators and 88% of principals in the United States either "strongly agree or agree they see great value in using digital learning tools in the classroom" (Gallup & NewSchools Venture Fund, 2019, p. 7). However, the literature highlights the challenges of emphasizing technology integration in teacher education programs and an overall lack of preparedness in regard to PSTs' technology integration abilities.

Teacher education programs have frequently sought to increase PSTs' knowledge and skills related to technology integration by adding a stand-alone technology integration course to the teacher education program requirements (Kleiner et al., 2007). While a recent meta-analysis

has found that stand-alone technology integration courses in teacher education programs significantly increased PSTs' knowledge of technology integration (Wilson et al., 2020), others argue that a single stand-alone course is not sufficient. For example, Lyublinskaya and Tournaki (2014) observed an increase in PSTs' knowledge in their study but noted that PSTs' application of this knowledge to mathematics and science lessons generally translated to using technology as a replacement to traditional practices rather than using technology to significantly impact either students' learning practices or their own pedagogical practices. Similarly, Graham et al. (2008) acknowledged this distinction between knowledge and application and sought to improve their teacher education program with a redesign that emphasized technology integration throughout all of PSTs' methods courses and included a field experience focused on technology integration. However, teacher education programs' adoption of such a model is lacking, as just 32% of the 44 teacher education programs sampled by Rose et al. (2017) provided K-8 PSTs with the opportunity to engage in technology experiences in an elementary classroom.

Though teacher education programs are working to improve their capacity to prepare PSTs' abilities to meaningfully integrate technology into their future classrooms, research has found that more work needs to be done. PSTs often report that they do not feel well-prepared to effectively utilize technological resources in their classrooms (Tondeur et al., 2012). Additionally, several studies have identified factors that help explain PSTs' feelings of unpreparedness, such as a lack of technology skills (Teo, 2009), lack of access to technology (Dawson, 2008), negative attitudes toward technology, or a lack of confidence in technology integration abilities (Crompton, 2015). Additionally, Crompton noted that the phenomenon of "apprenticeship of observation" as described by Lortie (1975) is especially influential with

mathematics PSTs, as PSTs may hold preconceived notions about what it means to teach mathematics due to their countless hours observing and evaluating teachers as a student themselves. Thus, if PSTs did not use (or rarely used) technology in the mathematics classroom as a student, it may be challenging for them to conceptualize how to appropriately use technology to enhance both students' mathematics learning and their own teaching practices.

Significance of K-8 PSTs' Technology Integration Preparedness

The significance of learning more about K-8 PSTs' preparedness to integrate technology into mathematics is echoed throughout several influential, guiding documents relevant to mathematics education. Additionally, due to the recent mass transition to an online learning environment during the COVID-19 pandemic, the need to understand more about PSTs' abilities to integrate technology is crucial.

In 2014, the National Council of Teachers of Mathematics (NCTM) published *Principles to Actions: Ensuring Mathematical Success for All*—building on their previous work (NCTM, 2000). Included in this prominent publication was six guiding principles for school mathematics, including: (a) teaching and learning, (b) access and equity, (c) curriculum, (d) tools and technology, (e) assessment, and (f) professionalism. NCTM (2014) notes that effective technology integration is especially beneficial for allowing students to visualize abstract mathematics concepts. This visualization promotes the development of students' conceptual understanding, which then acts as an agent in developing procedural fluency and other stands of mathematical proficiency (National Research Council, 2001). Similarly, the need to use technology in the mathematics classroom is echoed in the Mathematical Practices outlined in the Common Core State Standards for Mathematics, which states that students ought to "use

appropriate tools strategically," including: "paper and pencil, concrete models, a ruler, a protractor, a calculator, a spreadsheet, a computer algebra system, a statistical package, or dynamic geometry software" (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010, p. 7). This use of both concrete and technological tools relates to the concrete, representational, abstract (CRA) instructional sequence—based on the enactive, iconic, and symbolic stages of representation described by Bruner and Kenney (1965). When utilizing the CRA sequence, students first use concrete models (e.g., base-ten blocks, fraction strips), then representational models (e.g., drawings, virtual models), and finally abstract models (e.g., numbers, symbols) to examine a mathematics concept. Several studies have highlighted the beneficial impact of the CRA sequence on students' conceptual understanding of mathematics concepts—especially in regard to students with disabilities (see Bouck, Satsangi, et al., 2018). While technological resources are an important piece of the CRA sequence, their significance has grown exponentially in recent years.

With the onset of the COVID-19 pandemic, attending school online rather than in-person became the norm. As noted by the National Center for Education Statistics (2021), 65% of prekindergarten through twelve grade students were attending school either completely online or in a hybrid format with at least some online course meetings in February of 2021. Fittingly, recent research has adapted to the prevalence of online learning and modified the CRA sequence, producing the virtual, representational, abstract (VRA) sequence (Bouck et al., 2021; Park et al., 2021; Root et al., 2021). Likely due to the impracticality of utilizing concrete mathematics resources in an online setting, the VRA sequence recognizes the use of virtual models as a distinct stage in the instructional sequence. Additionally—since the virtual stage is the initial

stage in the sequence—the task of promoting the development of students' conceptual knowledge is now the responsibility of the capabilities of technological resources and teachers' abilities to appropriately and meaningfully utilize technology.

Given the inclusion of technology integration in several guiding documents of mathematics education and the significance of teachers' abilities to utilize technological resources in the classroom highlighted during the COVID-19 pandemic, it is crucial that we obtain additional information related to PSTs' preparedness to integrate technology into their future classrooms in order to best prepare them for future success.

Theoretical Framework

Great consideration was placed on determining which technology integration framework would guide the research of this dissertation. Ultimately, I selected the Passive, Interactive, and Creative—Replacement, Interactive, and Transformation (PICRAT) framework designed by Kimmons et al. (2020) due to its unique affordances. When creating the PICRAT model, Kimmons and colleagues evaluated existing technology integration models, provided an operational definition for each component of the PICRAT model, presented the hierarchical PICRAT matrix, and emphasized several affordances of the PICRAT model.

Evaluation of Existing Technology Integration Models

The PICRAT model was developed with seven theoretical models of technology integration in mind: (a) the Levels of Teaching Innovation (LoTi) framework (Moersch, 1995); (b) the Replacement, Amplification, and Transformation (RAT) model (Hughes et al., 2006); (c) the Substitution, Augmentation, Modification, and Redefinition (SAMR) model (Puentedura,

2003); (d) the Technology Acceptance Model (TAM; Venkatesh et al., 2003); (e) the Technology Integration Matrix (TIM; Welsh et al., 2011); (f) the Technology Integration Planning (TIP) model (Roblyer & Doering, 2013); and (g) the Technology, Pedagogy, and Content Knowledge (TPACK) framework (Koehler & Mishra, 2009). Kimmons and colleague's rationale for designing the PICRAT model was motivated by their assessment of existing technology integration theoretical models in the context of Kimmons and Hall's (2016) criteria for evaluating technology integration models for teacher education, including: (a) clarity, (b) compatibility, (c) fruitfulness, (d) role of technology, (e) scope, and (f) student focus. Kimmons and colleagues provided a guiding question for assessing technology integration models on each of these six criteria (Table 1.1). For each of the seven models, they discussed limitations in the context of teacher education.

Table 1.1. Evaluating Technology Integration Models

Criterion	Guiding Question
Clarity	Is the model sufficiently simple, clear, and easy to understand, with no hidden complexities?
Compatibility	Does the model complement/support existing educational practices deemed valuable to teachers?
Fruitfulness	Does the model elicit fruitful thinking as teachers grapple with problems of technology integration?
Role of technology	Does the model treat technology integration as a means for achieving specific pedagogical or other benefits (rather than an end in itself)?
Scope	Is the model sufficiently parsimonious to ignore aspect of technology integration not useful to teachers, but sufficiently comprehensive to guide their practice?
Student focus	Does the model clearly emphasize students and student outcomes?

Note. Adapted from "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 179 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

Kimmons et al.'s (2020) critique of the LoTi framework (Moersch, 1995) related to fruitfulness, as they claimed that the model contains too many levels and that the significance of level distinctions is unclear. The RAT model (Hughes et al., 2006) was contested by Kimmons and colleagues for issues related to clarity and student focus, as the transformation level (e.g., technology use that enables instructional practices) is easily misunderstood and students are not a central focus (e.g., the model only measures technology use in relation to teachers' practices). A commonly-used theoretical perspective—the SAMR model (Puentedura, 2003)—was challenged in regard to clarity, fruitfulness, and student focus. Kimmons and colleagues proposed that the level distinctions are vague (e.g., modification versus redefinition), the level distinctions may not be important for teachers, and that student activities are not explicitly defined at each level. Limitations of the TAM (Venkatesh et al., 2003) identified by Kimmons and colleagues included matters associated with compatibility, fruitfulness, role of technology, scope, and student focus. This model is researcher- or administrator-focused, provides minimal value for teachers, and does not treat technology as a means to a specific goal. Additionally, the TAM's scope is too narrow for teachers and students are excluded. The TIM (Welsch et al., 2011) received criticisms from Kimmons and colleagues on the criteria of clarity, fruitfulness, and scope. The 25 levels in the TIM are mutually inclusive and too numerous, as well as potentially being too specific for use as a self-improvement tool. Kimmons and colleagues noted limitations of the TIP model (Roblyer & Doering, 2013) related to clarity, scope, and student focus, as some terms are not sufficiently modeled, important aspects of teaching are not adequately addressed, and students are not the key focus. Lastly, the TPACK framework (Koehler & Mishra, 2009), was critiqued by Kimmons and colleagues in regard to clarity, compatibility, fruitfulness, and scope. The

TPACK framework has complex boundaries (e.g., organized as a three-circle Venn diagram), does not directly apply to classroom practices (e.g., the framework conceptualizes how various domains of knowledge contribute to teachers' technology integration abilities rather than assessing the impact of technology use on instruction), may not be empirically verifiable, and is potentially too broad for teacher use.

Prior to introducing the PICRAT model, Kimmons and colleagues noted that part of the reason that the existing technology integration models are not sufficient for teacher education is because most of the models were intended for broader/other purposes. Thus, while existing technology integration models are useful in a variety of contexts, they argued that a model specifically designed for teacher education is essential.

Operational Definition of the PICRAT Model

The PICRAT model is split into two portions. The first portion, PIC (passive learning, interactive learning, and creative learning), refers to three levels of students' relationship with the technological resource (Papert & Harel, 1991). For the second portion, Kimmons and colleagues adopted Hughes et al.'s (2006) RAT model as a lens through which the technology's impact on teachers' practices is examined. When utilizing the PICRAT model, the impact of technology integration is able to be assessed in relation to both students and teachers.

The PIC portion of the PICRAT model categorizes the way in which students will use a technological resource to engage with the content. Definitions and examples of each of the three levels of the PIC portion as described by Kimmons et al. (2020) are shown in Table 1.2. The distinctions between these levels are significant, as lasting, meaningful learning occurs more frequently during interactive learning when compared to passive learning, and even more so

during creative learning when compared to either interactive or passive learning (Kennewell et al., 2008). Additionally, Kimmons and colleagues noted that similar technological resources can be used to provide students with any of these three learning experiences. For example, a teacher could use GeoGebra—an online dynamic geometry environment—during a lesson on the formula for the area of a circle in a way that aligns with either passive, interactive, or creative learning. This could be accomplished by showing an informal proof of the formula on an interactive whiteboard (passive); allowing students to manipulate and rearrange fractional pieces of a circle using a personal laptop (interactive); or allowing students to create their own circles, approximate the area of the circle by creating and iterating radius squares or one-unit square tiles, and gather measurements to explore the relationship between the value of pi and both the area and radius measurements of various circles areas using a personal laptop (creative). Thus, the technological resource itself does not determine its designation in relation to the PIC portion of the PICRAT model, but rather the manner in which students use the technological resource to engage with the content.

Table 1.2. Passive, Interactive, and Creative

Level	Definition	Examples
Passive	Listening, reading, and observing	Reading lecture notes on PowerPoint slides, watching YouTube videos
Interactive	Exploring, experimenting, collaborating, and other active behaviors	Playing games, manipulating simulations, taking computerized adaptive tests
Creative	Constructing learning artifacts	Coding, editing videos, creating presentations

Note. Information from Kimmons et al. (2020).

The RAT portion of the PICRAT model categorizes the impact that the use of a technological resource has on teachers' pedagogical practices. Definitions and examples of each

of the three levels of the RAT portion as described by Kimmons et al. (2020) are shown in Table 1.3. Additionally, Kimmons and colleagues produced a flowchart to aid in categorizing technology integration in respect to the RAT portion of the PICRAT model and address the aforementioned issue related to the model's clarity, as shown in Figure 1.1. The distinctions between the levels of the RAT portion primarily pertain to students' learning outcomes and teachers' pedagogical practices. If technology integration does not clearly improve students' learning outcomes, it is categorized as replacement. If learning outcomes are improved but teachers' practices are not significantly impacted, the use of technology is categorized as amplification. Lastly, integration of technology that both improves learning outcomes and enables previously impractical pedagogical practices are categorized as transformation. Similar to Kimmons and colleagues' clarification in regard to the PIC portion of the PICRAT model, a use of technology's RAT designation does not solely rely on the technological resource. Rather, the RAT designation relies on how the use of technology impacts both students and teachers.

Table 1.3. Replacement, Amplification, and Transformation

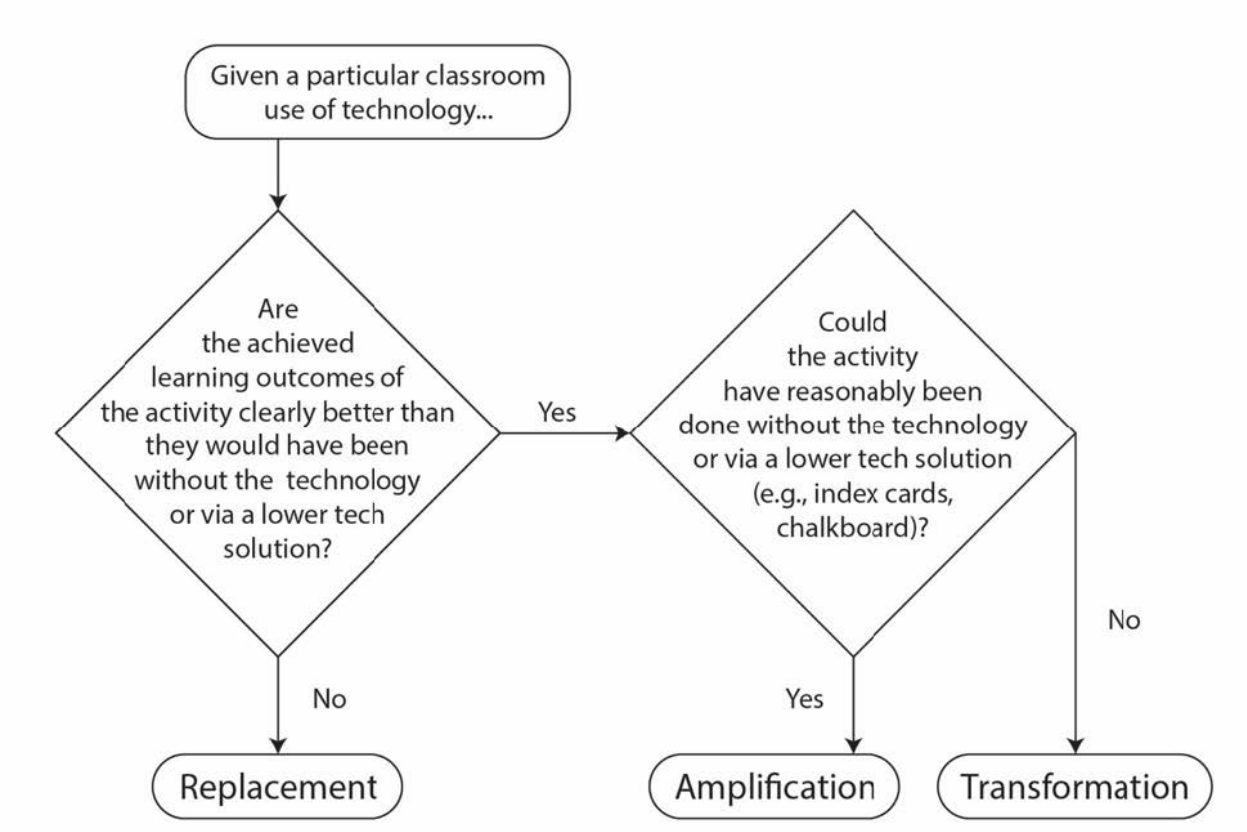
Level	Definition	Examples
Replacement	Technology use replaces a previous practice	Digital flashcards replacing paper flashcards, an interactive whiteboard replacing a chalkboard
Amplification	Technology use improves learning practices or outcomes	Using review features of Google Docs for more efficient feedback, using digital tools to collect data for analysis
Transformation	Technology use enables previously inconceivable or impractical pedagogical practices	Analyzing data using an online simulation, interviewing an expert at a university via Zoom

Note. Information from Kimmons et al. (2020).

Using the student-focused PIC and the teacher-focused RAT, Kimmons et al. (2020) organized the PICRAT model as a hierarchical matrix as shown in Figure 1.2. The matrix

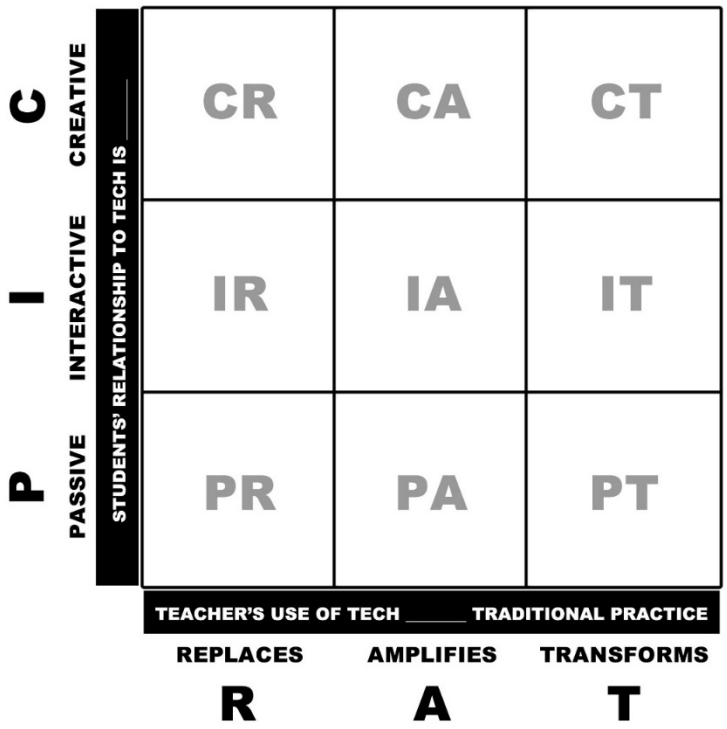
contains two guiding questions that can be used to identify an activity's use of technology in regard to both students' learning and teachers' pedagogical practices. Kimmons and colleagues note that this hierarchical matrix progresses from the bottom-left corner to the top-right corner in relation to the use of technology's overall impact on instruction. Distinct tiers of impact on instruction were not identified by the authors. However, when organized into equal-group tiers, "low-impact" levels would include PR, IR, and PA; "medium-impact" levels would include CR, IA, and PT; and "high-impact" levels would include CA, IT, and CR.

Figure 1.1. Replacement, Amplification, or Transformation Flowchart



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

Figure 1.2. The PICRAT Matrix



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

Affordances of the PICRAT Model

While recognizing that the model has not yet been validated with empirical studies, Kimmons et al. (2020) defended three beneficial characteristics of the PICRAT model based on their anecdotal experience in using the PICRAT model in teacher education courses. The first benefit relates to clarity, as the model is easy to remember, understand, and apply—especially in comparison to other technology integration models and due to the inclusion of the RAT flowchart. Compatibility is another benefit of the PICRAT model since it supports existing educational practices by "promoting innovative teaching and continually evolving pedagogy" and "encouraging teacher practices that use technology to put students in charge of their own

learning" (Kimmons et al., 2020, p. 192). The final benefit presented by Kimmons and colleagues relates to fruitfulness, as use of the PICRAT model may encourage meaningful self-reflection and conversations about using technology in the classroom. By focusing on the use of the technology rather than the technology itself, the PICRAT model encourages teachers to think about how the use of a technological resource might impact both their students' learning and their own pedagogical practices.

The potential benefits of the PICRAT model described by Kimmons et al. (2020) imply significant affordances to researchers. The benefit of clarity is especially valuable, as utilizing a clear model as a theoretical guide eases the process of designing and conducting a high-quality study. Using a model that is compatible with quality educational practices allows researchers to study technology integration within a framework that fosters beneficial pedagogical practices. Finally, the fruitfulness of the PICRAT model enables a perspective in which the actual use of a technological resource in the classroom is examined, rather merely focusing on the resource's characteristics.

Application of the PICRAT Model to Dissertation Research

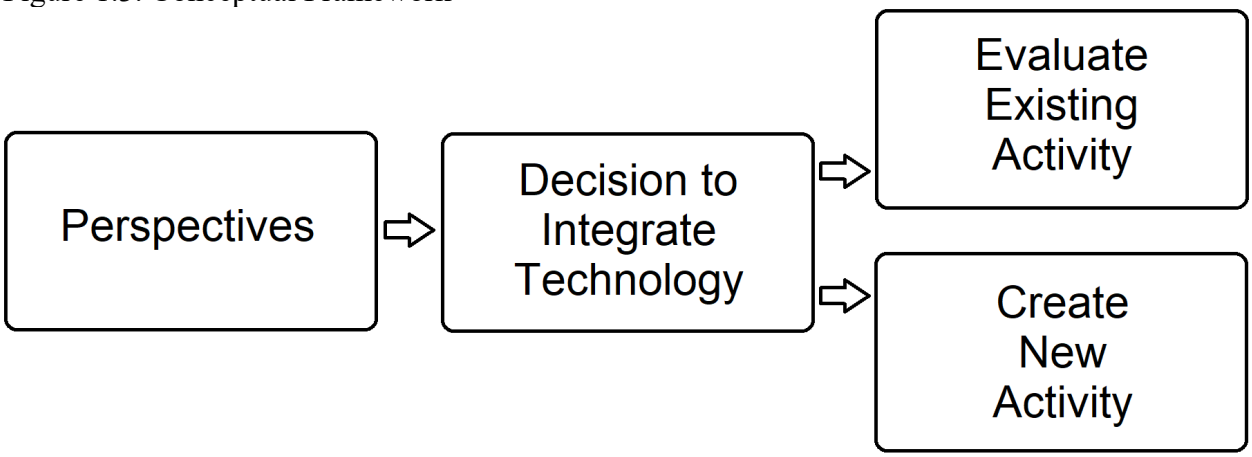
The PICRAT model guided each of the three independent manuscripts presented in this dissertation. First, technology integration was viewed through a lens that considered the impact of its use on both students' learning and teachers' practices. Additionally, the data collection process was informed by the PICRAT model, as the open-ended prompts used to gather data were worded in a way that would provide information in regard to both students and teachers. Similarly, the analysis of data and the interpretation of the findings were conducted through the lens of the PICRAT model. Due to the recency of the publication of the PICRAT model, the first

manuscript utilized both the PICRAT model and Puentedura's (2003) SAMR model. Since the SAMR model is commonly-used throughout the literature, this dual approach helped to verify the reliability of the PICRAT model and establish its validity by comparing these findings to those found when using the SAMR model.

Conceptual Framework

The focus of this dissertation research is on K-8 PSTs' preparedness to integrate technology into mathematics. Since the sample consists of PSTs who are not yet completing their student teaching experiences, it is difficult to examine their *demonstrated* technology integration practices. Thus, each of the three manuscripts in this dissertation focuses on different influences of technology integration that occur prior to implementation—essentially the "planning stage." PSTs' perspectives—such as their perceived knowledge of technology integration and attitudes toward technology integration—have been discussed in the literature as factors contributing to PSTs' technology integration practices and abilities (e.g., Crompton, 2015). When considering PSTs' technology integration practices and abilities, I make a distinction between the two options that one has after deciding to integrate technology into an upcoming lesson: (a) locate, evaluate, and potentially modify an existing activity that utilizes a technological resource or (b) create a new activity that utilizes a technological resource. Thus, the guiding conceptual framework of this dissertation research, as shown in Figure 1.3, highlights the relationship between the research topics of each manuscript.

Figure 1.3. Conceptual Framework



Overview of the Three-Manuscript Structure

All three manuscripts employed a qualitative, social constructivist paradigm, in which the views and opinions of participants are highlighted when forming an understanding of reality (Creswell & Poth, 2017). Additionally, each manuscript utilized an ethnographic approach to examine and describe the shared culture (e.g., attitudes, values, concepts, beliefs, and practices) of K-8 PSTs in regard to technology integration in mathematics (Mills & Gay, 2018). Lastly, the PICRAT model guided the design, data collection, data analysis, and interpretation of the findings in all three manuscripts.

Each manuscript examined K-8 PSTs enrolled in a K-8 Math Methods course at a large postsecondary institution in the Northwest region of the United States. PSTs were enrolled in an undergraduate elementary education program that led to initial teacher licensure for grades K-8. Additionally, the vast majority of the sample for each manuscript consisted of White females and PSTs were generally in their third or fourth year of undergraduate study.

In the second and third manuscripts, the mathematics strand of geometry was utilized as the context. The decision to focus on a specific strand of mathematics was based on the potential

that PSTs' abilities to evaluate/create activities that utilize a technological resource rely on their content knowledge related to the activity. More so, geometry was selected as the content area due to the importance of visualization when examining geometry concepts and the potential for geometry activities to align with all of the levels of the PICRAT model.

The first manuscript focused on K-8 PSTs' perspectives on and anticipated practices for integrating technology in mathematics. The research questions of this study were the following:

Q1. What knowledge of technology integration in mathematics do K-8 PSTs possess?

Q2. What questions/concerns do K-8 PSTs have regarding technology integration in mathematics?

Q3. What are K-8 PSTs' anticipated technology integration practices for their future mathematics classrooms?

Q4. For K-8 PSTs' proposed uses of technology in mathematics, how would the technological resource impact mathematics instruction?

The primary goals of this study were to gain an understanding of PSTs' perspectives on integrating technology into their future mathematics classrooms, examine how frequently they anticipate they will integrate technology, and analyze how they intend to integrate technology. In addition, this manuscript utilized the SAMR model as a theoretical framework as a supplement to the PICRAT model. This dual approach was implemented to provide a comparison for the PICRAT model due to the recency of its development and publication.

The second manuscript focused on K-8 PSTs' evaluation of existing geometry activities that utilize a virtual resource. The research questions of this study were the following:

Q1. In existing geometry activities that utilize a technological resource evaluated by K-8 PSTs, how would the resource impact mathematics instruction?

Q2. What do K-8 PSTs like about existing geometry activities that utilize a technological resource?

Q3. What do K-8 PSTs dislike about existing geometry activities that utilize a technological resource?

Q4. What characteristics of existing geometry activities that utilize a technological resource inform K-8 PSTs' interest in implementing the activity in their future classrooms?

The primary goal of this study was to gain an understanding of how PSTs' evaluate existing geometry activities that utilize a virtual resource, as the literature on this topic is lacking. Additionally, due to the availability of technological resources relevant to mathematics education, locating a ready-made resource that aligns with the objectives of a lesson is an efficient lesson-planning strategy for teachers. In theory, PSTs' abilities to evaluate an existing activity that utilizes a technological resource may impact the likelihood that they integrate technology into their future classrooms.

The third manuscript focused on K-8 PSTs' creation of geometry activities that utilize a virtual resource. The research questions of this study were the following:

Q1. In geometry activities that utilize a technological resource created by K-8 PSTs, how would the resource impact mathematics instruction?

Q2. How do K-8 PSTs anticipate that their future students might perform in geometry activities that utilize a technological resource that they created?

Q3. What pedagogical considerations do K-8 PSTs specify when creating geometry activities that utilize a technological resource?

While this study focused on the impact that the technological resource utilized in PSTs' activities would have on mathematics instruction, information regarding several pedagogical considerations (i.e., anticipated student learning outcomes/challenges and methods of assisting students or addressing challenges) were also explored. In alignment with this dissertation's conceptual framework, the creation of activities was examined independently from the evaluation of activities as these are potentially different skills.

Three Manuscripts' Relation to the Overall Purpose of the Dissertation

As highlighted in the conceptual framework (Figure 1.3), the three previously described manuscripts focus on distinct aspects of the "planning stage" of integrating technology. The first manuscript examined K-8 PSTs' perspectives on and anticipated practices for technology integration in mathematics, which likely has an impact on whether they will choose to integrate or not integrate technology into a lesson (Crompton, 2015). Assuming that a PST decides that they would like to utilize a technological resource for a given lesson, the second and third manuscripts investigate the two options that the PST has moving forward: evaluate an existing activity or create a new activity. These two options were separated into distinct manuscripts due to the fact that successfully completing either option likely demands a somewhat different skill set from PSTs. Additionally, PSTs' implementation of activities that utilize a technological resource could not be analyzed in this dissertation research as the PSTs recruited for the studies had not yet entered their student teaching experiences. Thus, these three manuscripts provided an

in-depth examination of multiple aspects of K-8 PSTs' perspectives, anticipated practices, and abilities related to the "planning stage" of technology integration.

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CHAPTER TWO

K-8 PRESERVICE TEACHERS' TECHNOLOGY INTEGRATION IN MATHEMATICS: PERSPECTIVES AND ANTICIPATED PRACTICES

Contribution of Authors and Co-Authors

Manuscript in Chapter 2

Author: Monte Meyerink

Contributions: Monte designed the study, recruited participants, collected and analyzed data, interpreted findings, and wrote the manuscript in preparation for submission.

Co-Author: Fenqjen Luo

Contributions: Fenqjen supervised the study, analyzed data, interpreted findings, and edited the manuscript in preparation for submission.

Manuscript Information

Monte Meyerink and Fenqjen Luo

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Abstract

This qualitative, ethnographic study sought to examine kindergarten through eighth-grade preservice teachers' ($N = 19$) perspectives on technology integration within the context of mathematics. Topics of primary interest were preservice 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 preservice teachers often described students' use of mathematical games. Additionally, this study found that preservice 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.

Introduction

The integration of technology into kindergarten through eighth-grade (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, Web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge" (Moyer et al., 2002, p. 373), 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 preservice teachers (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. Currently, 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). However, 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). Additionally, 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). Gaining additional information regarding PSTs' perspectives on technology integration may prove beneficial to teacher education programs, current PSTs, and future PSTs.

The intent of this study was to examine current K-8 PSTs' perspectives on technology integration in mathematics. 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. Thus, the research questions in this study included the following:

Q1. What knowledge of technology integration in mathematics do K-8 PSTs possess?

Q2. What questions/concerns do K-8 PSTs have regarding technology integration in mathematics?

Q3. What are K-8 PSTs' anticipated technology integration practices for their future mathematics classrooms?

Q4. For K-8 PSTs' proposed uses of technology in mathematics, how would the technological resource impact mathematics instruction?

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.

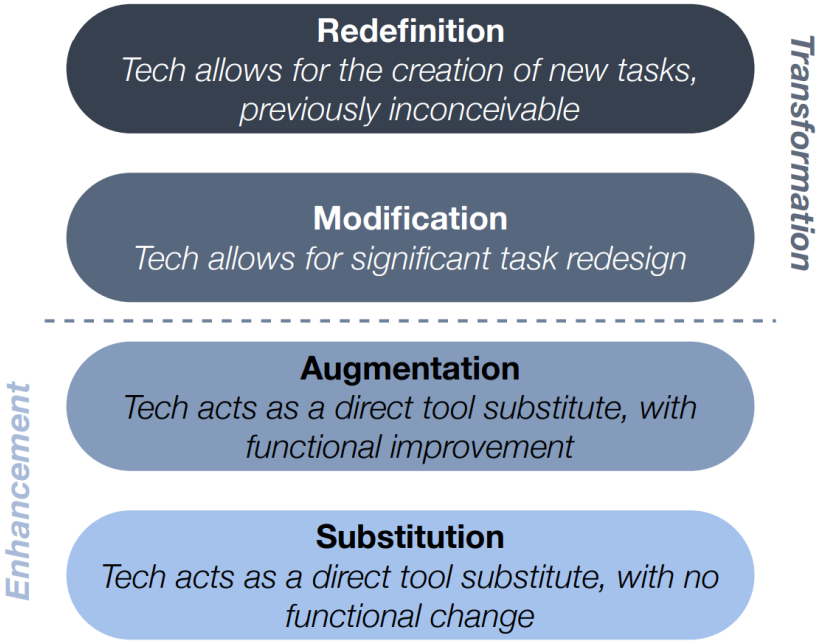
The SAMR Model

Puentedura's (2003) SAMR model offered a means by which the impact of technological resources on mathematics instruction may be categorized. Figure 2.1 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 2.1. The SAMR Model



Note. From *Ruben R. Puentedura's Blog*, by R. R. Puentedura, 2003-2021, Hippasus, (http://hippasus.com/blog/). CC BY-NC-SA 3.0.

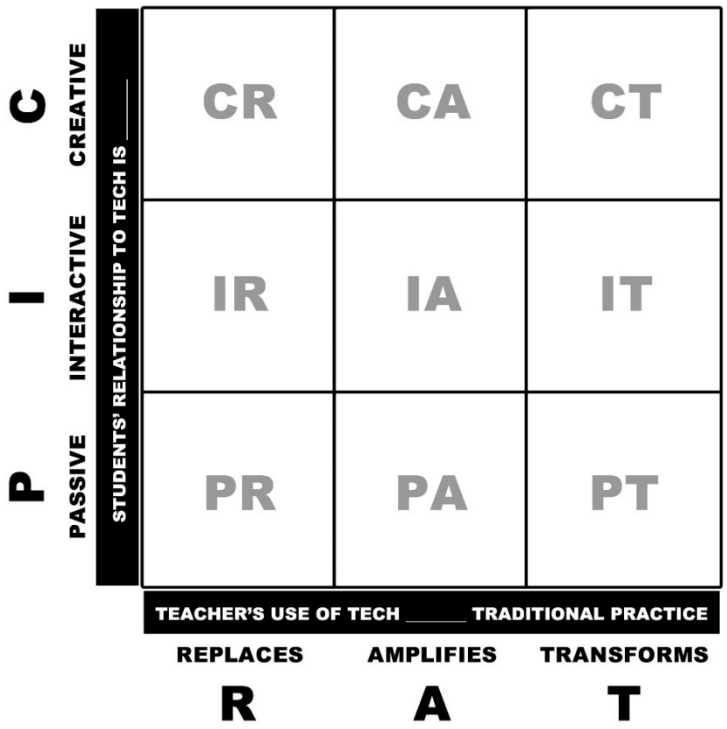
While the SAMR model is often utilized in technology integration research, the model is not without criticism. In fact, a portion of the rationale to create the PICRAT model was Kimmons and colleagues' critique of the SAMR model and other existing technology integration

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.

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 may be analyzed. The PICRAT model is organized into a hierarchical matrix (Figure 2.2) 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.

Figure 2.2. The PICRAT Matrix



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

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 practices. Examples include analyzing data with online simulations or interviewing an expert with a video conferencing service.

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.

Methodology

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, an ethnographic approach was applied to "describe,

analyze, and interpret the culture of a group;" in which "culture is the set of attitudes, values, concepts, beliefs, and practices shared by members of a group" (Mills & Gay, 2018, p. 379). Thus, this study gathered individual responses to prompts and artifacts to examine the culture of a group of K-8 PSTs regarding their perspectives on technology integration in mathematics. While this study did not gather longitudinal data—which is common in ethnographic research—the researchers had continuous interactions with participants through the duration of the semester due to their roles as course instructors. Additionally, the researchers classified this research approach as an ethnography due to the study's goal of describing PSTs' shared culture in the context of technology integration.

Researcher Positionality

Social constructivism recognizes that reality is co-constructed between the researchers and research participants (Creswell & Poth, 2017). Therefore, it is important that the researchers situate themselves in the context of this study. At the time of this writing, the first author is a doctoral candidate studying mathematics education and an instructor of K-8 Math Methods. Comparable to the PSTs in this study, he was an education major as an undergraduate student, having completed similar courses and field experiences. He has a strong interest in educational technology and the implications of technology use on students' learning. The second author is an associate professor of mathematics education and instructor of K-8 Math Methods. She has over ten years of experience teaching both undergraduate and graduate courses for both PSTs and in-service teachers at the research site. As the instructors of the research site, the researchers recognized the potential for power or status differentials between PSTs and themselves, which may have an impact on their willingness to participate in this study and/or their responses to

prompts. They were aware of this possibility and were mindful of their own biases, beliefs, and experiences with PSTs when recruiting participants and collecting, analyzing, and interpreting PSTs' responses.

Context, Population, and Sample

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 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.

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

Table 2.1. 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 (include 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 (include 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?

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 2.1). PSTs submitted their responses to the researchers online with a learning management system. 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 were 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. After identifying preliminary codes, each researcher independently applied this preliminary codebook to each PST's responses to each prompt. The researchers then compared their coding, assessed the interrater reliability (IRR), 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 to represent IRR as percent agreement (e.g., what percent of codes were the same for both coders). 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.

Methods of Achieving Validity

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.

Results

Of the PSTs recruited for this study, 19 of 24 (79.2%) consented that their responses may be analyzed for research purposes. 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. 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.

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 (What knowledge of technology integration in mathematics do K-8 PSTs possess?) was examined with PSTs' responses (n = 19) to P1, "What do you know about using educational technology in the mathematics classroom?" 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).

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.

Table 2.2. PSTs' Knowledge of Technology Integration

Theme	*n*	PSTs' Responses
Lack of knowledge	7	• 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	• 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	• Khan Academy for math videos • GeoGebra, Tinkercad • Google Classroom
Mathematical games	5	• Learning games that involve math concepts/strategies • Math-based computer games
Specific technological resources	4	• Chromebooks • SMART Boards, calculators, and document cameras

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 2.2. 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.

Questions/Concerns Regarding Technology Integration

The second research question (What questions/concerns do K-8 PSTs have regarding technology integration in mathematics?) was investigated with PSTs' responses (n = 18) to P2,

"What questions/concerns do you have about using educational technology in the mathematics classroom?" 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 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.

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.

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 2.3. 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 2.3. PSTs' Technology Integration Questions and Concerns

Theme	n	PSTs' Responses
When/how to integrate technology	6	• 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	• 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	• 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	• Kids getting off track and doing things they aren't supposed to • My biggest concern would be students 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), "How frequently do you plan on using educational technology in the mathematics classroom?" and P6 (n = 19), "What do you think is the most practical application of technology in K-8 mathematics, and why?" provided insight in regard to the third research question (What are K-8 PSTs' anticipated technology integration practices for their future mathematics classrooms?). 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.

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.

Table 2.4. PSTs' Anticipated Technology Integration Frequency

Theme	*n*	PSTs' Responses
Very frequently	3	• 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	• 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	• 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	• I think I would use technology less within the classroom when it comes to math
Very infrequently	2	• 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 2.4. 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.

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.

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 2.5. 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.

Table 2.5. PSTs' Perspectives on the Most Practical Application of Technology Integration

Theme	*n*	PSTs' Responses
Student practice	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	• Assessments where questions can vary (harder and easier) would be another good use of technology in a math classroom • Widely used in assessments
Differentiation	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	• 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] manipulates by decreasing clean up time, distractions, and transitions in the lesson

Impact of Technological Resources on Mathematics Instruction

The fourth research question (For K-8 PSTs' proposed uses of technology in mathematics, how would the technological resource impact mathematics instruction?) was examined with PSTs' responses to P4 (n = 18), "Find one resource (include the URL) and answer the following questions: (a) For what grade level and CCSS 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.)." and P5 (n = 19), "Locate one resource (include the URL) and describe how you might use this resource to assess understanding in your future classroom." 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. 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.

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.

Figure 2.3. Osmo's Tangram Game



Note. From *Genius Tangram*, by Osmo, 2022, Tangible Play. (https://www.playosmo.com/). Copyright 2022 by Tangible Play. Reprinted with permission.

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 2.3—to examine, compose, and decompose various shapes and figures using both physical and virtual modalities simultaneously.

Discussion

The findings of this study uncovered information relevant to both researchers and teacher educators. The two-pronged theoretical approach of this study highlighted the utility of the PICRAT model and provided a direct comparison between the PICRAT and SAMR models. Additionally, the findings in regard to PSTs' perspectives on technology integration—especially their lack of technology integration knowledge, questions/concerns about how to integrate technology, technology integration intentions, and tendency to integrate technology in ways that align with IA/augmentation—suggest that PSTs need additional training in order to be adequately prepared to meaningfully integrate technology upon degree completion.

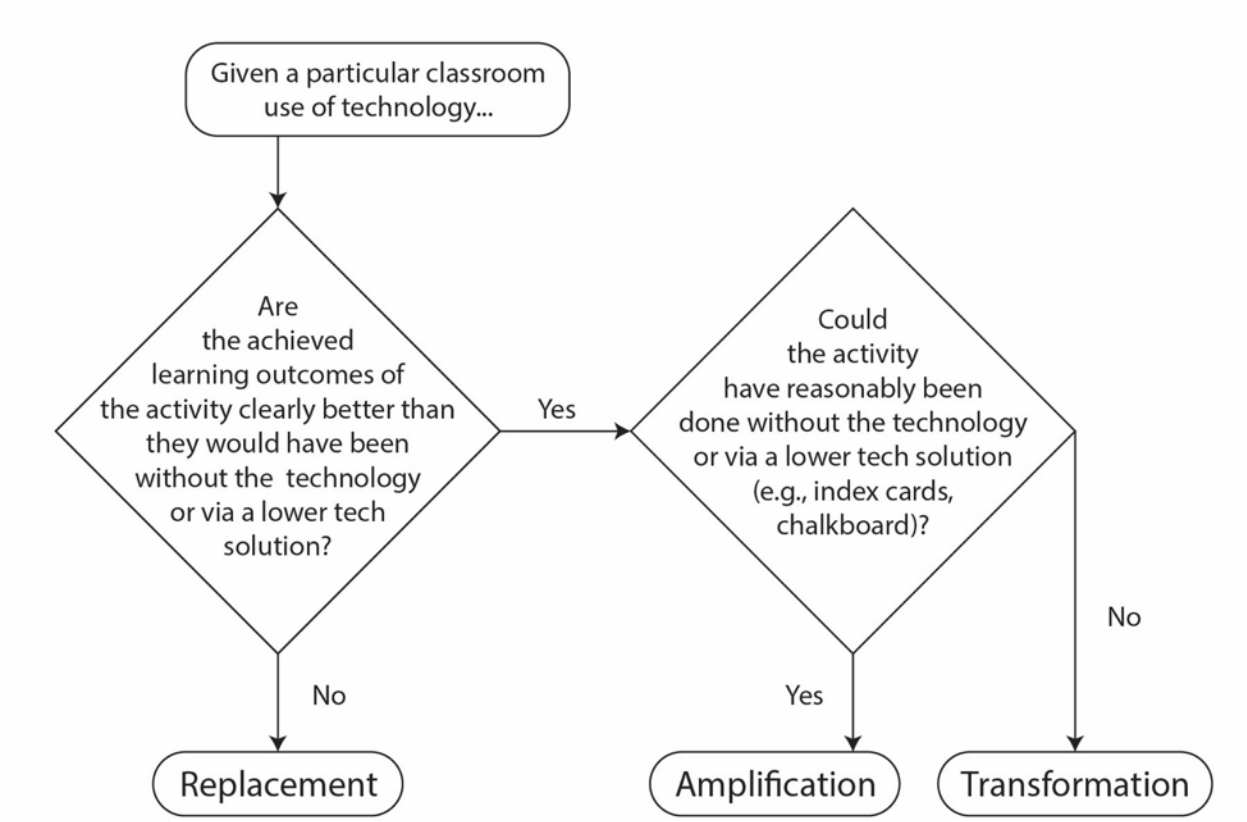
Comparison of the PICRAT and SAMR Models

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 2.4. 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.

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.

Figure 2.4. PICRAT Flowchart for the RAT



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

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?) 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?) 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?) 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?) 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.

Limitations

The primary limitation of this study relates to external validity, as this study examined a 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. Lastly, 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.

Implications of Findings and 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.

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. 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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CHAPTER THREE

K-8 PRESERVICE TEACHERS' EVALUATION OF EXISTING GEOMETRY ACTIVITIES THAT UTILIZE A TECHNOLOGICAL RESOURCE

Contribution of Authors and Co-Authors

Manuscript in Chapter 3

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Contributions: Monte designed the study, recruited participants, collected and analyzed data, interpreted findings, and wrote the manuscript in preparation for submission.

Co-Author: Fenqjen Luo

Contributions: Fenqjen supervised the study, analyzed data, interpreted findings, and edited the manuscript in preparation for submission.

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Abstract

Prior research has highlighted the importance of integrating technology into mathematics education, though preservice teachers often do not feel prepared to integrate technology into their classroom upon degree completion. This qualitative, ethnographic study sought to examine kindergarten through eighth-grade preservice teachers' ($N = 44$) evaluation of existing geometry activities that utilize a technological resource. Specifically, the researchers examined the impact that the technological resource utilized in the activity would have on instruction, aspects of the activity that preservice teachers either liked or disliked, and preservice teachers' rationale as to why they would choose to either use or not use the activity in their future mathematics classrooms. To guide the methodology of this study, the researchers utilized the PICRAT model. Data were collected from responses to an open-ended prompt as part of a mathematics methods course and analyzed with both *a priori* (i.e., PICRAT) and emergent coding. Findings from the *a priori* coding showed that the activities evaluated by preservice teachers most frequently utilized a technological resource (often a mathematical game) in a way that aligned with the interactive, amplification level of the PICRAT model. The emergent coding found that preservice teachers most frequently liked the content of the activity, disliked topics related to the pedagogical implications of implementing the activity, and founded their rationale for future use on pedagogical implications related to implementation. Implications of the findings are discussed as well as recommendations for future research.

Introduction

Technology integration in kindergarten through eighth-grade (K-8) mathematics has becoming an increasingly relevant topic in the twenty-first century—especially in recent years due to the prevalence of online instruction and reduction of in-person instruction during the COVID-19 pandemic. According to the National Center for Education Statistics (NCES), just 35% of prekindergarten through twelfth grade students in the United States were enrolled in in-person instruction in February of 2021 (NCES, 2021). While NCES noted this percentage increased to 50% by May of 2021 and will likely continue to increase as schools begin to offer more opportunities for in-person instruction, the pandemic has highlighted the need for teachers to be able to effectively integrate technology into their classroom.

A theoretical approach to mathematics education that can be observed throughout the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) is the concrete, representational, abstract (CRA) sequence—based on Bruner and Kenney's (1965) stages of representation: enactive, iconic, and symbolic. When informed by the CRA sequence, mathematics instruction includes both teachers' presentation of concepts and students' exploration of concepts in a sequence that utilizes: (a) concrete models, such as base-ten blocks or fraction tiles; (b) representational models, such as drawings or virtual models; and (c) abstract models, such as mathematical symbols and numbers. The use of the CRA sequence has been found to be especially beneficial in developing students' conceptual understanding of various mathematics concepts (Flores et al., 2018; Flores et al., 2014; Flores & Milton, 2020; Milton et al., 2019). As one can imagine, utilizing concrete models is likely impractical when delivering instruction in an

online setting. This lack of access to concrete models likely increases the importance of utilizing technological resources when allowing students to explore mathematics concepts, such as utilizing a virtual version of a geoboard (e.g., https://apps.mathlearningcenter.org/geoboard/) when a physical geoboard is unavailable. Especially in online settings where concrete models may be inaccessible, the use of representational models, including virtual models, is likely crucial for the development of students' conceptual understanding of mathematics concepts.

Research has shown that numerous applications of educational technology in the K-8 mathematics classroom have been beneficial to several aspects related to students' mathematics outcomes. Two of the most-frequently researched technological resources in relation to mathematics education are virtual manipulatives and mathematical games. Research has shown that the use of such resources have been beneficial to students' outcomes in mathematics, such as their conceptual understanding (Reimer & Moyer, 2005; Suh & Moyer, 2007), achievement on assessments (Brezovszky et al., 2019; Kiger et al., 2012), attitudes toward mathematics (Lee & Chen, 2015; Sen et al., 2017), and confidence (Yuan et al., 2010). The use of both mathematical games and/or virtual manipulatives are especially useful when exploring geometry concepts, as these technological resources allow teachers to align their instruction with the CRA sequence by providing students with opportunities to explore virtual representations of various two- and three-dimensional shapes.

Given the current relevance of technology integration, the research-based benefits of technology use in K-8 mathematics, and the potential to align geometry instruction with the CRA sequence by utilizing technological resources, it is crucial that K-8 preservice teachers (PSTs) are prepared to integrate technology into their future mathematics classrooms. However, research

has uncovered the PSTs often feeling unprepared to integrate technology into the classroom upon entering the field as an in-service teacher (Tondeur et al., 2012). Prior studies have reported findings related to this feeling of unpreparedness, such as a lack of technology skills (Teo, 2009), negative attitudes toward technology integration, and a lack of confidence in their ability to meaningfully integrate technology (Crompton, 2015). When deciding how to integrate technology into the classroom, teachers logically have two options: (a) locate an existing activity that utilizes a technological resource and conduct an evaluation of the activity or (b) create a new activity that utilizes a technological resource. However, little research has examined technology integration through a perspective that honors this distinction. Thus, research that examines the process of how PSTs plan to integrate technology while noting the distinction between evaluating and creating a technology-infused activity may be beneficial to our understanding of K-8 PSTs' abilities to integrate technology into mathematics.

In their analysis of in-service secondary mathematics teachers, McCullough et al. (2018) examined factors that influenced teachers' integration of technology into mathematics lessons. They reported aspects of technological resources that teachers liked and disliked, highlighted teachers' rationale for utilizing specific resources, and summarized teachers' experiences using technology to teach secondary mathematics. However, after a thorough review of the literature, no studies were located in which a similar approach was applied to K-8 PSTs. Therefore, the approach utilized in McCullough and colleagues' study informed the research design in this examination of K-8 PSTs.

The intent of this study was to examine K-8 PSTs' evaluation of existing geometry activities that utilize a technological resource. Specifically, the researchers were interested in the

impact that the technological resource would have on instruction, the specific aspects of the activity that PSTs either liked or disliked, and PSTs' rationale as to why they would choose to either use or not use the activity in their future K-8 mathematics classrooms. Thus, the research questions in this study included the following:

Q1. In existing geometry activities that utilize a technological resource evaluated by K-8 PSTs, how would the resource impact mathematics instruction?

Q2. What do K-8 PSTs like about existing geometry activities that utilize a technological resource?

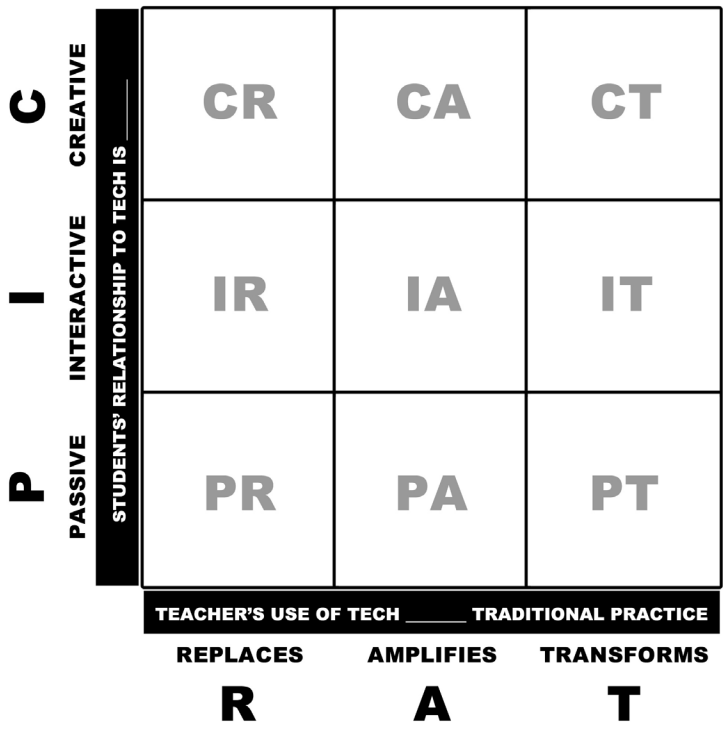
Q3. What do K-8 PSTs dislike about existing geometry activities that utilize a technological resource?

Q4. What characteristics of existing geometry activities that utilize a technological resource inform K-8 PSTs' interest in implementing the activity in their future classrooms?

Theoretical Framework

The guiding theoretical lens of this study was Kimmons et al.'s (2020) Passive, Interactive, and Creative—Replacement, Amplification, and Transformation (PICRAT) model which allowed the researchers to examine the impact of technology integration in regard to both students' relationship to technology and teachers' pedagogical practices. Organized as a hierarchical matrix (Figure 3.1), the PICRAT model contains nine distinct levels that classify technology's impact on instruction in respect to the perspective of both students and teachers.

Figure 3.1. The PICRAT Matrix



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

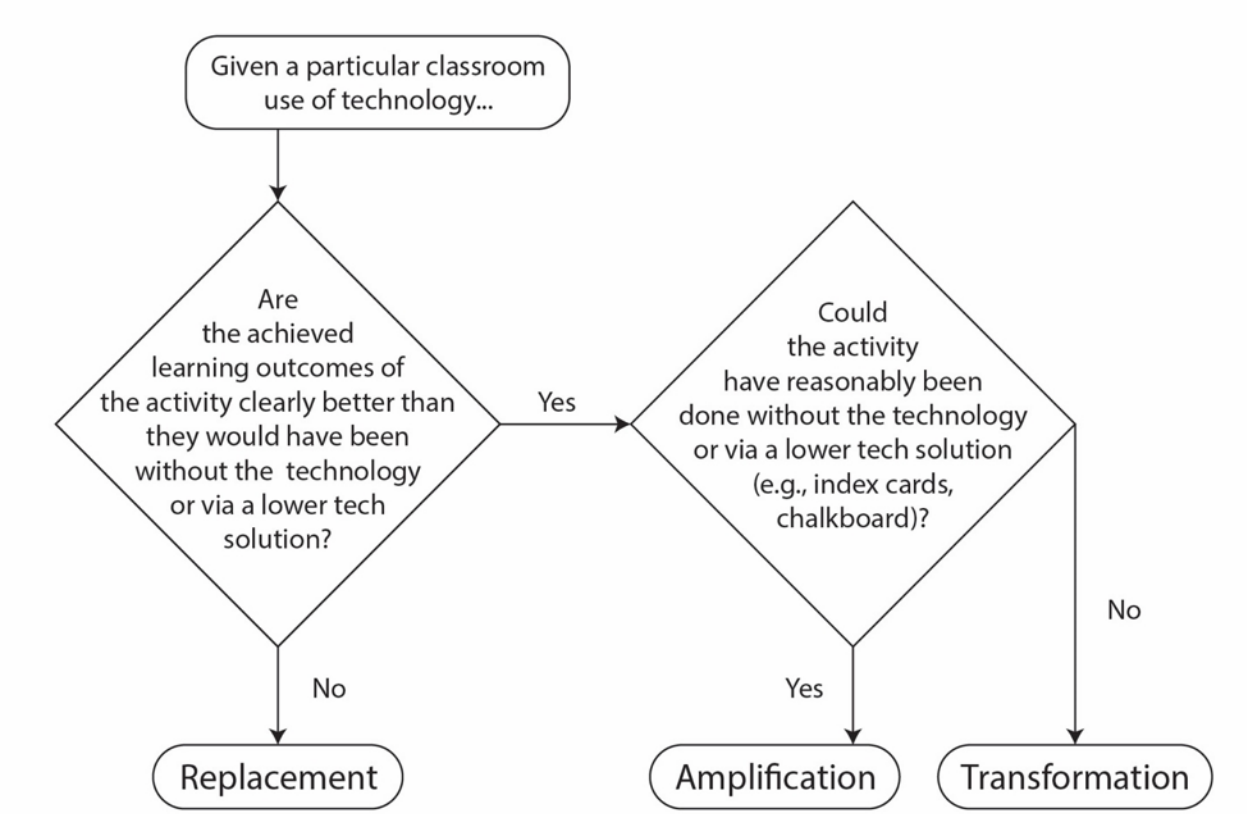
The PIC portion of the PICRAT model describes how students use a technological resource during instruction. In the first level—passive learning—students are using technology to receive content passively, such as by reading notes on a PowerPoint, listening to an audiobook, or watching a YouTube video. Kimmons and colleagues (2020) noted that while passive modes of learning are essential, they are not sufficient learning skills. The second level is interactive learning, in which students use technology to explore, experiment, collaborate, and engage in other active behaviors—such as playing games or manipulating dynamic models. While interactive learning promotes lasting, meaningful learning (Kennewell et al., 2008), the learning that occurs in such activities is largely structured by the technology rather than by the student.

The final level—creative learning—transcends this limitation by allowing students to use technology to create learning artifacts, such as writing computer code or constructing virtual figures with dynamic mathematics software. Instances of creative learning best promote lasting, meaningful learning as students apply concepts and skills to create artifacts to solve problems (Papert & Harel, 1991). Kimmons and colleagues noted that focusing on students' use of technology may prevent the erroneous practice of assigning educational value to the technology itself (e.g., "GeoGebra is a high-quality resource, so any activity in which students use GeoGebra is a high-quality activity"). By reflecting on the PIC portion of the PICRAT model, teachers are forced to more closely examine how students will use technology during instructional activities and consider the pedagogical benefits of this technology use.

For the second portion of the PICRAT model, Kimmons et al. (2020) adopted the RAT model proposed by Hughes et al. (2006) which describes how the use of technology impacts teachers' practices. The first level is replacement, in which technology is used to replace a previous practice (e.g., using an interactive whiteboard instead of a chalkboard) without any functional improvement. Kimmons and colleagues noted that while replacement is not necessarily poor practice, it does not provide substantial benefits to students' learning outcomes. At the second level—amplification—technology use enables some degree of enhancement to students' learning practices or outcomes (e.g., using review features of a word processor for efficient feedback or using digital devices to gather data for analysis). While amplification improves teachers' practice, Kimmons and colleagues stated that it does not drastically change pedagogy. The final level is transformation, in which the use of technology enables a previously inconceivable or impractical pedagogical practice (e.g., using a virtual simulation to analyze

data). Integrating technology at the transformation level allows teachers to implement underutilized pedagogical practices and provide students with unique learning experiences. To aid in the process of determining the RAT level with which a particular use of technology aligns, Kimmons et al. supplemented their descriptions with the flowchart shown in Figure 3.2.

Figure 3.2. PICRAT Flowchart for the RAT



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

In this study, the PICRAT model guided the data collection, data analysis, and interpretation of the findings. In regard to data collection, the prompts utilized were designed in a way that would provide information in relation to both students' and teachers' use of technology.

The data analysis was heavily impacted by the PICRAT model as it was employed as an *a priori* codebook. Additionally, the interpretation of the findings was conducted through the lens of the PICRAT model by relating the findings to the distinctions identified in the PICRAT model.

Methodology

A social constructivist, qualitative paradigm was utilized in this study in order to seek understanding regarding K-8 PSTs' evaluation of geometry activities that utilize a technological resource. In social constructivism, understanding of the world is sought by relying on the views of participants (Creswell & Poth, 2017). Through the lens of social constructivism, an ethnographic approach was applied to examine the culture of K-8 PSTs in regard to evaluating geometry activities that utilize a technological resource, in which "culture is the set of attitudes, values, concepts, beliefs, and practices shared by members of a group" (Mills & Gay, 2018, p. 379). Thus, this study collected and analyzed K-8 PSTs' responses in order to describe the culture of PSTs' evaluation of geometry activities that utilize a technological resource. The researchers interacted with participants numerous times throughout the semesters due to their roles as course instructors. While this study did not gather longitudinal data, the researchers considered this research to be ethnographic due to the study's goal of describing PSTs' shared culture in the context of evaluating K-8 geometry activities that utilize a technological resource.

Researcher Positionality

A social constructivist perspective recognizes the co-construction of reality that occurs between researchers and research participants (Creswell & Poth, 2017). Due to this recognition, the researchers must situate themselves in relation to the context of this study in order to increase

transparency. At the time of this writing, the first author is a doctoral candidate studying mathematics education and an instructor of K-8 Math Methods. He has a strong interest in researching PSTs' experiences with educational technology and their abilities to integrate technology into their future mathematics classrooms. The second author is an associate professor of mathematics education and is an instructor of K-8 Math Methods as well. She has taught both undergraduate and graduate mathematics education courses at the research site for over ten years. Since the researchers are instructors of K-8 Math Methods, they recognized the potential for power and/or status differentials between themselves and the participants of this study. These differentials may have had an impact on PSTs' willingness to participate in this study and/or their responses to the prompts utilized for data collection. The researchers were aware of this potential and were conscious of their personal biases, beliefs, and experiences with PSTs when recruiting participants, collecting data, analyzing data, and interpreting the findings.

Context, Population, and Sample

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 ($N = 44$) of this study were recruited from an undergraduate mathematics methods course (i.e., K-8 Math Methods). One section of the course during both the spring and fall semesters of 2021 were utilized for recruitment. All participants were enrolled in the aforementioned course and working toward a bachelor's degree in elementary education with licensure to teach grades K-8. Participants were in either their penultimate or final year of the teacher education program, and many would be completing their student teaching experience in the semester following the mathematics methods course. Thus, the population of this study was PSTs who are

undergraduate students at the research site, enrolled in their third or fourth year of an elementary education program, and enrolled in K-8 Math Methods.

In each section of the K-8 Math Methods course, participants engaged in a two-day lesson (two 75-minute periods) on K-8 geometry during the fifteenth week of each semester. In this lesson, PSTs explored theories, pedagogical considerations, and mathematics content relevant to K-8 geometry. Based on the K-8 geometry topics presented by Van de Walle et al. (2018), PSTs learned about: (a) van Hiele's (1959/1984) levels of geometric thought and its influence on geometry curricula; (b) the CRA sequence (Bruner & Kenney, 1965) and its significance in relation to students' learning of geometry; and (c) K-8 geometry content with a focus on shapes and properties due to the emphasis of this strand of geometry as seen in the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). PSTs completed several in-class activities during this lesson, such as: (a) describing how van Hiele's theory is useful to teachers, (b) demonstrating the implementation of the CRA sequence for a specific K-8 geometry standards, and (c) using GeoGebra to illustrate various geometry concepts.

Data Collection

Data were collected following the previously described two-day lesson on K-8 geometry. Notably, data collection occurred in April and November of 2021 during the COVID-19 pandemic. The creation of the prompt used for data collection was informed by both the PICRAT model and McCullough et al.'s (2018) examination of factors that influenced secondary mathematics teachers' integration of technology into mathematics. To examine K-8 PSTs'

evaluation of geometry activities that utilize a technological resource, PSTs were asked to respond to the following prompt:

> Locate an existing geometric thinking and/or geometric concepts activity that utilizes a technological resource (e.g., GeoGebra) and respond to the following prompts: What do you like about the activity? What do you dislike about the activity? Why would you choose to either use or not use this activity in your future classroom?

PSTs submitted their responses to this prompt to the researchers via a learning management system. Responses were initially downloaded as individual files and later organized into a Microsoft Excel spreadsheet. When organizing the data into a spreadsheet, PSTs' names were removed and replaced with identification numbers in order to ensure confidentiality.

Data Analysis

Separate analyses were conducted in relation to each research question. To address the first research question, the researchers utilized the PICRAT model as an *a priori* codebook. Each PST's response was coded as passive, interactive, or creative (PIC), and replacement, amplification, or transformation (RAT) by each of the researchers. In cases where the use of technology could potentially be coded as multiple levels, the researchers selected the level that aligned with the most prominent use of technology in the activity. The researchers compared their initial coding, discussed and made changes that were deemed necessary, and assessed the interrater reliability (IRR). To provide a description of the activities evaluated by PSTs and address the second, third, and fourth research questions, the researchers utilized emergent coding following the theme-identifying strategy of repetition. As described by Ryan and Bernard (2003), repetition identifies themes on the basis of the frequency at which a topic occurs and reoccurs in a given response from participants. In alignment with Creswell and Poth's (2017)

recommendations for emergent coding, the researchers established a coding platform (i.e., Microsoft Excel spreadsheet) and cooperatively developed a list of preliminary codes in relation to each research question. Next, each researcher independently applied the preliminary codebooks to each PSTs' response. They then compared their coding, made changes that were deemed necessary following discussion, and assessed the IRR of their coding. Following the recommendation of Creswell and Poth, the researchers represented IRR as percent agreement, or the percentage of codes that were the same for both researchers. After calculating the IRR for both the *a priori* and emergent coding, the researchers met to make final edits to the coding to allow for the presentation of the frequency of each code for each research question.

Methods of Achieving Validity

While the concept of qualitative validity is debated, Creswell and Poth (2017) described how various methods can be employed to increase several constructs related to the validity of a study. To increase the dependability, we presented rich descriptions of our research procedures to ensure that others can follow and critique our decisions. The confirmability of our findings were increased by including detailed descriptions of the data (i.e., verbatim responses from PSTs) and thoroughly discussing the data analysis procedures utilized in this study. Our complete description of the site, population, and sample clearly established the appropriate transferability of the findings. We sought to increase this study's authenticity by positioning ourselves in relation to the context in which this study occurred. Lastly, the reliability of our findings was increased by utilizing multiple coders, assessing the IRR, and employing peer review throughout the writing process.

Results

Of the 53 PSTs recruited for this study, 22 from each course section ($N = 44$, 83.0%) consented that their responses may be analyzed for research purposes. Of this sample that agreed to participate in this study, all but three PSTs had adequately responded to the prompt utilized for data collection. The missing data occurred in the portion of the prompt that asks, "What do you dislike about the activity?" Since these three PSTs had adequately responded to the other portions of the prompt, they were only excluded from the analysis of the third research question and were retained for the other analyses. An analysis based on demographic factors (e.g., gender, race/ethnicity, year in program, undergraduate major, etc.) was not possible due to the characteristics of the recruited sample. The vast majority of participants were White females in their third or fourth year of the elementary education program. Therefore, analyses based on demographic factors was excluded due to the lack of variance in these factors.

After the researchers' individually coded the data, the IRR of both the *a priori* and emergent coding was calculated. In regard to the *a priori* coding in alignment with the PICRAT model, the researchers attained an IRR of 93.2% (41/44) for the PIC portion of the model and an IRR of 88.6% (39/44) for the RAT portion of the model, and an IRR of 81.8% (36/44) for the PICRAT model overall. For the emergent coding, the researchers attained an IRR of 95.5% (42/44) when coding the types of technological resources utilized in PSTs' activities, an IRR of 93.2% (41/44) when coding what PSTs liked about the activities, an IRR of 80.5% (33/41) when coding what PSTs disliked about the activities, and an IRR of 88.6% (39/44) when coding PSTs' rationale for future use of the activities. Overall, the emergent coding in this study achieved a mean weighted IRR of 89.6% (155/173). Additionally, it is worth noting that the sample differed

on the emergent coding since three PSTs did not specify what they disliked about the activity. Creswell and Poth (2017) recommend a minimum IRR of 80%, so the results presented in regard to both the *a priori* and emergent coding in this study are acceptable.

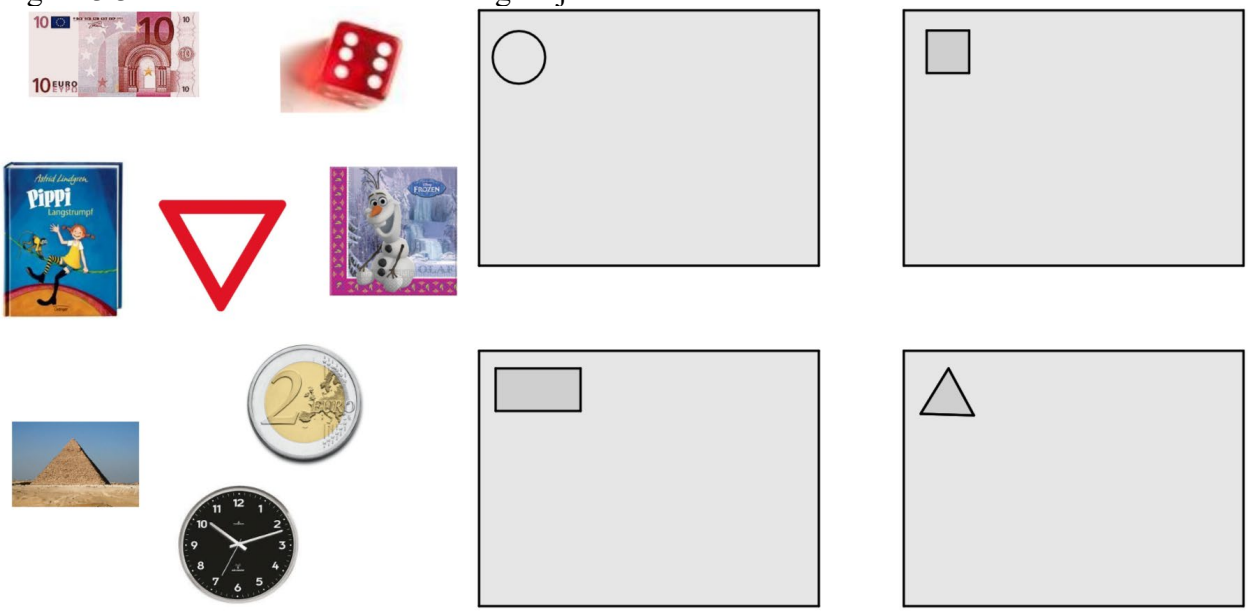
Table 3.1. Type of Technological Resource Utilized in Activities Evaluated by PSTs

Resource Type	*n*	Examples
Mathematical game	30	• Sorting geometric shapes (https://www.geogebra.org/m/wHnByPks#material/bgY4rBep) • Identifying geometric shapes (https://mrnussbaum.com/shape-factory-online-game) • Identifying types of triangles (https://www.splashlearn.com/s/math-games/identify-types-of-triangles)
Virtual manipulative	13	• Interactive tangram puzzle (https://www.geogebra.org/m/zrGERP88) • Dynamic geometry environment (https://www.geogebra.org/m/tzdtevu7) • Interactive proof environment (https://canfigureit.com/)
Virtual demonstration	3	• Informal proofs of properties of triangles (https://www.geogebra.org/m/JVc49sEa) • Definitions of points, lines, and planes (https://www.geogebra.org/m/z2FSQCSv#material/KV8xXxLF) • Constructing the Twitter logo with circles of varying radii and color (https://www.geogebra.org/m/TtXNqBv6)

To provide a more detailed description of the activities evaluated by PSTs, the researchers used emergent coding to examine the types of technological resources that the activities utilized. The analysis found that three different types of resources were utilized in the activities evaluated by PSTs, as seen in Table 3.1. Most PSTs (n = 30, 68.2.%) chose to evaluate an activity that utilized a mathematical game while others evaluated an activity that utilized a virtual manipulative (n = 13, 29.5%) or a virtual demonstration of a mathematics concept (n = 3, 6.8%). Likely due to the lesson's focus on geometric shapes and properties, many PSTs

evaluated an activity that utilized a mathematical game in which students were asked to sort and various geometric shapes based on their appearance, such as the game shown in Figure 3.3.

Figure 3.3. GeoGebra Game for Sorting Objects



Note. From "Sort the Objects According to Their Shape," by GeoGebra Team German & GeoGebra Translation Team German, 2022, *GeoGebra* (https://www.geogebra.org/m/wHnByPks#material/BYSURwXc). CC BY-NC.

Impact of Technological Resources on Mathematics Instruction

To address the first research question (In existing geometry activities that utilize a technological resource evaluated by K-8 PSTs, how would the resource impact mathematics instruction?), PSTs' responses were coded in alignment with the *a priori* codebook of the PICRAT model. Each researcher coded each response as either passive, interactive, or creative (PIC) and either replacement, amplification, or transformation (RAT). Codes were based on both the affordances of the technological resources utilized in the activities as well as PSTs' descriptions of how the activity could be implemented into the K-8 mathematics classroom. Additionally, each PST's response was coded as a single level of the PICRAT model.

Frequencies and examples of PSTs' responses that aligned with each observed PICRAT level are shown in Table 3.2. Notably, no activities evaluated by PSTs utilized technology in a way that aligned with the PT (passive, transformation); IT (interactive, transformation); or CR (creative, replacement) levels of the PICRAT model.

Table 3.2. Activities Through the Lens of the PICRAT Model

PICRAT Level	*n*	Examples
PR	1	• Reading definitions of points, lines, and planes (https://www.geogebra.org/m/z2FSQCSv#material/KV8xXxLF)
PA	6	• Completing a non-interactive quiz that provides instant feedback (https://www.mathgames.com/skill/1.5-count-edges-vertices-and-faces)
IR	5	• Composing/decomposing shapes with an interactive tangram puzzle (https://www.geogebra.org/m/zrGERP88)
IA	29	• Playing interactive games that provide instant feedback (https://www.geogebra.org/m/wHnByPks or https://www.geogebra.org/m/DNC5JUDD)
CA	2	• Creating shapes in a dynamic geometry environment (https://www.geogebra.org/m/tzdtevu7)
CT	1	• Creating proofs in an interactive geometry proof environment (https://canfigureit.com/)

Nearly two-thirds (n = 29, 65.9%) of the activities evaluated by PSTs utilized technology in alignment with the IA (interactive, amplification) level of the PICRAT model. Activities coded as IA most commonly included the use of games in which students could drag geometric shapes into various categories (e.g., circles, triangles, squares, rectangles, prisms, pyramids, etc.) and also included games where students would be asked to classify three-dimensional shapes based on the properties of their two-dimensional nets. These technological resources were coded as interactive because students would need to interact with the resource (e.g., drag or rotate geometric shapes or nets) in order to study the mathematics content. The rationale for coding

these resources as amplification was frequently associated with a resource's ability to provide instant feedback to individual students. This capability would likely improve students' learning outcomes but would not likely have a significant impact on a teacher's pedagogical practice since the activities could reasonably been implemented without technology. Five PSTs (11.4%) evaluated activities that utilized technology in alignment with the IR (interactive, replacement) level of the PICRAT model. Activities coded as IR included the use of virtual manipulatives in which students could drag two-dimensional shapes to engage in composition and decomposition (e.g., tangram puzzles). These interactive technological resources were coded as replacement since they did not include any form of feedback to students, so students' learning outcomes would likely not significantly differ had the same activity been implemented without the use of technology.

Seven of the activities evaluated by PSTs utilized technology in a way that promoted passive learning, with six (13.6%) aligning with the PA (passive, amplification) level and one (2.3%) aligning with the PR (passive, replacement) level of the PICRAT model. In these activities, students would not interact with the technological resources in a meaningful way or use the resources to create mathematical representations. Rather, students would primarily engage in passive learning, such as reading or observing. Activities coded as PA included the use of games in which students would be quizzed on the properties of geometric shapes or composition of nets, videos of informal proofs of properties of triangles, and a slider-controlled demonstration of the construction of the Twitter logo. These activities were coded as amplification because they either incorporated instant feedback, efficiently presented informal proofs, or modeled complex mathematical representations, all of which would potentially

improve students' learning outcomes. The activity coded as PR was a virtual list of definitions of points, lines, and planes. This activity was coded as replacement because the information could realistically be presented without technology (i.e., whiteboard) while maintaining students' learning outcomes.

Just three PSTs evaluated an activity that utilized technology in a way that enabled students' creative learning, with two (4.5%) aligning with the CA (creative, amplification) level and one (2.3%) aligning with the CT (creative, transformation) level of the PICRAT model. In these activities, students would use the technological resources to create geometric shapes or geometry proofs. Activities coded as CA utilized a dynamic geometry environment (i.e., GeoGebra), in which students could create and examine various two-dimensional shapes. These were coded as amplification due to the potentially beneficial impact of efficiency on students' learning outcomes and the capability to reasonably implement the activity with a lower technology solution (e.g., whiteboard, geoboard, etc.). The activity coded as CT was an interactive geometry proof environment in which students could manipulate geometric shapes and construct proofs of various theorems. This activity was coded as transformation due to its potential to improve students' learning outcomes due to the inclusion of instant feedback and both the efficiency and clarity of the virtual models. Additionally, this use of technology would likely transform a teachers' pedagogical practices since the activity could not be implemented without the use of technology.

Liked Aspects of Activities

The second research question (What do K-8 PSTs like about existing geometry activities that utilize a technological resource?) was investigated by examining PSTs' responses to the

portion of the prompt that asked, “What do you like about the activity?” The emergent coding identified seven themes, which were organized into three primary categories: (a) content, (b) technological design, and (c) pedagogy. Content themes included the quality of mathematics content, the use of relevant contexts, and the variety of content included in the activity. Technological design themes included the technology’s ease of use and the interactive nature of the technology. Pedagogy themes included the activity’s inclusion of instant feedback and the capability to scaffold instruction when using the activity. Frequencies and examples of PSTs’ responses that informed each observed theme are shown in Table 3.3. Since each PST’s response could potentially be coded as multiple themes, the sum of the frequencies in Table 3.3 is greater than the sample size.

Of the three primary categories, the largest proportion of PSTs discussed topics related to the content of the activity when reporting aspects of the activity that they liked. Within this category, the most frequently discussed theme was the quality of mathematics content, which was mentioned by 17 PSTs (38.6%). Specifically, PSTs liked activities that would allow students to compare various two- and/or three-dimensional shapes based on their properties (e.g., parallel sides, right angles, etc.). PSTs also liked when activities included a wide variety of shapes for students to examine (n = 10, 22.7%) and when activities utilized a context that was relevant to students (n = 9, 20.5%), such as using a coin instead of a circle or a fish tank instead of a rectangular prism.

Table 3.3. What PSTs Liked About the Activities

Theme	*n*	PSTs' Responses
Content		
Mathematics content	17	• [The activity] requires students to focus on the properties of each of the shapes as well as what classes the shape fall into • I like that this resources gets students to think not only about the 3D shape of a figure, but also what the net of a 3D shape may look like
Variety	10	• [Students] can practice comparing many different shapes including circles, squares, quadrilaterals, etc. • I like that the shapes students are asked to classify are in different orientations and sizes
Relevant context	9	• The activity uses everyday objects so students feel like what they are learning is relevant • This activity has excellent real-world application since students are sorting common objects that they will see in their everyday lives
Design		
Ease of use	8	• I like this activity because it is very simple and easy to use • I like that this website is very easy to navigate—it has clear instructions and also has pictures to help guide the students • I really like how easy the program was to use—the points are very clear, the directions were easy, and the goal of the activity was concise and specific
Interactive	6	• [The activity] allows students to physically move a shape into its proper category • The activity provides a ruler that students can use to measure both length and right angles
Pedagogy		
Feedback	7	• The activity gives automatic feedback • [The activity] will show a green check when students get the correct answer
Scaffolding	7	• I like that this activity has a series of activities to work through—this allows for scaffolding, for students to build upon their knowledge, and work their way toward understanding more difficult concepts as they go along • I like that [the activity] progressively gets harder

Several PSTs noted that they liked specific design aspects of the technological resource utilized in the activity. Eight PSTs (18.2%) liked the ease of use of the technological resources—often citing the inclusion of clear instructions and well-functioning mechanics. Additionally, six PSTs (13.6%) mentioned that they liked the interactive design of the technological resource. Examples highlighted by PSTs include resources in which students could drag shapes into categories, reposition shapes to practice composition and decomposition, or drag a virtual ruler to measure the side lengths of shapes.

Lastly, PSTs also liked the pedagogical implications of implementing the activity. Several PSTs (n = 7, 15.9%) noted the benefits of activities in which instant feedback was included. In the activities evaluated by PSTs, the feedback generally identified solutions as either correct or incorrect but rarely included further explanation of the rationale for correctness or incorrectness. Additionally, 15.9% of PSTs (n = 7) highlighted the activity's potential to be used to scaffold mathematics instruction. PSTs suggested that scaffolding would be possible when implementing activities due to the order in which the components of the activities were presented, with initial tasks being easier to complete and later tasks obtaining an increasingly challenging level of difficulty.

Disliked Aspects of Activities

PSTs' responses to the portion of the prompt that asked, "What do you dislike about the activity?" were examined to address the third research question (What do K-8 PSTs dislike about existing geometry activities that utilize a technological resource?). The emergent coding identified six themes, which were organized into three primary categories: (a) content, (b) technological design, and (c) pedagogy. Content themes included a misleading representation of

mathematics concepts and the limited assortment of content included in the activity. The only technological design theme was structural aspects of the technology that restricted students' use in some way. Pedagogy themes included the lack of instant feedback and the activity having a limited application in the classroom. The final theme identified was PSTs reporting that there was nothing that they disliked about the activity. Additionally, it is worth noting that the sample size of this specific analysis was $n = 41$, as three PSTs did not provide a response to this portion of the prompt utilized for data collection. Frequencies and examples of PSTs' responses that informed each observed theme are shown in Table 3.4. Since each PST's response could potentially be coded as multiple themes, the sum of the frequencies in Table 3.4 is greater than the sample size.

When discussing aspects that they disliked about the activities, PSTs most frequently discussed topics related to the pedagogical implications of implementing the activity in a classroom. Many PSTs ($n = 16$, 39.0%) mentioned disliking that the activity they evaluated because they felt that the activity would only be applicable in a limited number of settings. For example, PSTs stated that activity: (a) was repetitive and would quickly become boring to students, (b) would not provide students with a challenge, (c) could only be used with young or struggling students, or (d) did not provide opportunities to scaffold instruction for students who would benefit from extension activities. Additionally, some PSTs ($n = 4$, 9.8%) disliked that the activity did not provide students with adequate feedback as to whether their solutions were correct or incorrect.

Table 3.4. What PSTs Disliked About the Activities

Theme	*n*	PSTs' Responses
Pedagogy		
Limited application	16	• One thing is dislike about this activity is that there is no room for extension—it is pretty basic and does not give a lot of room for students to grow • [The activity] could only be useful for a certain age level • This activity can become boring for students since it is repetitive
Inadequate feedback	4	• I dislike that there is no way for students to check their work after they have classified all of the shapes • [The activity] does not tell [students] why answers are wrong or how to think differently • I do not like that [the activity] does not tell [students] the correct answer
Content		
Limited content	11	• I wish this activity had more templates for students to try and fit smaller shapes into • I wish there was an option to change the shape…to see more than just the parallelogram • There is no way to…add any additional geometric solids for students to sort
Misleading mathematics	3	• This activity does not emphasize the different between 2D and 3D shapes…the [2D] poster and [3D] dice are designated as the same [shape] • The students can only classify squares as squares—I would make it so students could classify the square as both a square and a rectangle
Design		
Restrictive structure	13	• [The activity] does not allow for the [3D] shapes to be rotated…this would be helpful for a student who struggles to visualize the whole shape • What I do not like about this activity is that it will not let [students] drag a shape into the [incorrect] side • I do not like that this activity does not include images of the triangles
Nothing	4	• I do not have anything I dislike about this activity • I actually like everything about this activity

Additionally, PSTs discussed aspects related to the content of the activity when highlighting what they disliked about the activity. Several PSTs (n = 11, 26.8%) disliked that the activity included a limited amount of content—generally referring to the variety of shapes that were present in the activity. A small group of PSTs (n = 3, 7.3%) disliked that the mathematics content included in the activity was somewhat misleading. In these cases, PSTs were speaking of an activity that would ask students to sort both two- and three-dimensional shapes, such as the GeoGebra game previously shown in Figure 3.3. However, the categories into which shapes could be sorted were labeled with the names of two-dimensional shapes. Thus, in order to reach the "correct" solution in this activity, students would have to place some three-dimensional shapes into categories labeled as two-dimensional shapes (e.g., placing a picture of a pyramid into the category for triangles).

Specific design aspects of the technological resource utilized in the activity were disliked by several PSTs (n = 13, 31.2%). The only theme that aligned with this category was PSTs reporting that the structure of the resource was somewhat restrictive. Generally, PSTs who discussed this topic suggested additional features that could be added to the technological resource to make the activity more valuable to students' learning. Some improvements that PSTs suggested included: (a) the ability to rotate three-dimensional shapes, (b) the ability to decompose three-dimensional shapes into nets, (c) the ability to move shapes into incorrect categories, and (d) the inclusion of additional resources (e.g., virtual ruler, coordinate grid, or images of shapes).

Lastly, a small group of PSTs (n = 4, 9.8%) noted that there were no aspects or characteristics of the activity that they disliked. This group only includes PSTs who provided a

response to, “What do you dislike about the activity?” Thus, this group does not include the three PSTs who did not provide a response to this portion of the prompt, as they were excluded from the analysis of this research question.

Rationale for Future Use of Activities

To analyze the fourth research question (What characteristics of existing geometry activities that utilize a technological resource impact K-8 PSTs’ interest in implementing the activity in their future classrooms?), PSTs’ responses to the portion of the prompt that asked, “Why would you choose to either use or not use this activity in your future classroom?” were examined. The emergent coding identified six themes, which were organized into three primary categories: (a) content, (b) technological design, and (c) pedagogy. The only content theme was the activity’s inclusion of valuable mathematics content. The only technological design theme was the engaging nature of the technology utilized in the activity. Pedagogy themes included the activity’s potential to be used to either introduce, practice, or review content. The final theme identified was PSTs’ lack of specification as to why they either would or would not use the activity in their future classroom. Additionally, the vast majority of PSTs (n = 41, 93.2%) reported that they would use the activity in their future classroom (e.g., “I would definitely use this resource” or “I would use these activities”). Two PSTs reported that they would maybe use the activity in the future (e.g., “I am not 100% sure if I would use this [activity] in the classroom or not”) while just one PST did not plan to use the activity (e.g., “I would probably not use [the activity]”). Frequencies and examples of PSTs’ responses that informed each observed theme are shown in Table 3.5. Since each PST’s response could potentially be coded as multiple themes, the sum of the frequencies in Table 3.5 is greater than the sample size.

Table 3.5. PSTs' Rationale for Future Use of Activities

Theme	*n*	PSTs' Responses
Pedagogy		
Introduce content	12	• I could use this to introduce properties of parallelograms • I would…use [the activity] as an introduction tool to help students identify different 3D shapes around the classroom • I would use this [activity] in my classroom to introduce the topic of using properties to identify a shape
Review content	10	• I would use this activity in my classroom as a quick, whole-class refresher before starting a lesson • I would use this resource…as a review…of 3D shapes • I would most likely use this resource…before a quiz for students to refresh their memories
Practice content	9	• [The activity] is good practice because it gives immediate feedback • I think this activity provides students with a good opportunity to practice classifying different sizes and orientations of shapes • I would use this [activity] for specific students who may need extra practice
Content		
Valuable mathematics content	11	• Because this activity and all of its components are so thorough, it will allow students to build a solid understanding of the concept of geometric nets • This is a great visual to show how the sides and angles can be the same and different • I like that [the activity] has real-life examples—I think it is important to connect math to real life
Design		
Engaging	6	• I like that…it could be a really engaging [activity] for younger students • [The activity] can get students interested in concepts of geometry by including something that they…enjoy • I would use this [activity] in my future classroom because it is a fun, interactive way for students to strengthen their mathematical thinking
Not Specified	9	• I would absolutely use this in my classroom

The majority of PSTs based their rationale for future use of the activity they evaluated on various topics related to the pedagogical implications of implementing the activity. In responses that aligned with the pedagogy category, PSTs discussed various purposes of implementing the activity. Most reported that they would use the activity to either introduce (n = 12, 27.3%) or review (n = 10, 22.7%) content, but several also suggested that the activity could be implemented to allow students to practice newly-learned content or as a supplemental activity (n = 9, 20.5%). In addition, it is worth noting that the two PSTs who reported they would maybe use their evaluated activities in the future based their rationale on the potential to use the activity to either review content or have students practice content.

One quarter of PSTs (n = 11, 25.0%) stated that their decision to either use or not use the activity in their future classroom was based on the activity's inclusion of valuable mathematics content. PSTs reported that these activities would likely help students improve their understanding of: (a) the properties of different shapes, (b) the relationships between the properties of shapes, (c) the connection between two- and three-dimensional shapes, and (d) the application of shape to "real-world" phenomena. The one PST who stated they would not use the activity they evaluated in their future classroom indicated that a lack of valuable mathematics content informed their decision, as they "could find or create something that is more rigorous for the students."

Few PSTs (n = 6, 13.6%) discussed technological design features when presenting their rationale as to why they would use the activity in their future classrooms. In these responses, PSTs generally discussed concepts related to engagement, such as students likely enjoying the technological resource or having fun while working with interactive, virtual models.

Additionally, several PSTs (n = 9, 20.5%) did not specify their rationale as to why they would choose to use or not use the activity in the future classroom. In these cases, PSTs generally stated that they would use the activity in the future but did not provide specific characteristics of the activity that informed their interest in future implementation.

Discussion

The findings of this study highlighted the need for continued research on PSTs' technology integration abilities. The vast majority of PSTs reported that they would like to implement the activity they evaluated in their future classrooms. However, PSTs' tendency to select an activity that utilized technology in a way that aligned with the IA level of the PICRAT model suggests that additional training in technology integration may be needed in order for PSTs to be prepared to integrate technology in a more impactful manner (e.g., integration that aligns with the CA, IT, or CT levels of the PICRAT model). Additionally, this study added to the literature by assessing the reliability of using the PICRAT model as an *a priori* codebook and providing an example of utilizing the PICRAT model as a theoretical framework.

The PICRAT Model

Due to the recency of the publication of the PICRAT model, the authors feel that it would be beneficial to describe their experience with using the model as an *a priori* codebook. While the authors obtained an acceptable IRR for the PICRAT model, they did experience some challenges in coding activities as a single PICRAT level. The design of the PICRAT model implies mutual exclusivity between the levels (e.g., learning cannot simultaneously be both passive and interactive, technology cannot simultaneously both replace and amplify instruction,

etc.). However, the authors argue that the distinctions between levels are not as binary as suggested—especially when examining the use of technology over an extended time period (e.g., a single activity, one lesson, an entire unit, etc.). For example, some activities evaluated by PSTs in this study used the same technological resource in a way that aligned with different levels of the PICRAT model at different points in time during the activity (i.e., using GeoGebra to first present information [i.e., passive learning] and then allowing students to use GeoGebra to manipulative and experiment with different shapes [i.e., interactive learning]). A potential method for increasing the utility of the PICRAT model could be to assess technology's impact on instruction over time rather than as a single, summative snapshot. More so, quantitative analyses might consider weighted observations over time (e.g., 5 minutes of PR and 15 minutes of IA) to obtain a more precise representation of how technology is being used in the classroom.

Impact of Technological Resources on Mathematics Instruction

The findings of the *a priori* coding in alignment with the PICRAT model in regard to Q1 (In existing geometry activities that utilize a technological resource evaluated by K-8 PSTs, would does the resource impact mathematics instruction?) found that the activities evaluated by PSTs most frequently aligned with the IA level of the PICRAT model (65.9%). Notably, very few PSTs (6.8%) evaluated activities that utilized technology in alignment with high-impact levels of the PICRAT model (e.g., CA, IT, and CT). These findings align with those of prior research, as Meyerink and Luo (2022) found that K-8 PSTs' proposed uses of technology in mathematics most frequently aligned with the IA level of the PICRAT model with few instances aligned with high-impact levels. Similarly, K-8 in-service mathematics teachers classified their own technology-infused activities as amplification when evaluating activities in relation to the

RAT portion of the PICRAT model (Thomas & Edson, 2019). While mathematical games were utilized in many of the evaluated activities, several activities utilized virtual manipulatives such as geoboards, pattern blocks, or tangrams—aligning with the findings of Moyer-Packenham et al. (2008).

Overall, these findings are encouraging as most PSTs evaluated and considered the future use of an activity that utilized technological resources in a way that fostered students' interactive learning and amplified teachers' instruction. However, findings also suggest that additional training may need to be integrated into teacher education programs in order to promote uses of technology that align with the high-impact levels of the PICRAT model. Recommendations from the literature for technology integration training that may promote PSTs' high-impact uses of technology include: (a) explicit modeling of high-impact practices by teacher educators (Foulger et al., 2017), (b) experience using the PICRAT model (Kimmons et al., 2020), or opportunities to use technology in K-8 classrooms (Graham et al., 2008). That being said, it is unclear whether or not teacher educators can or should expect PSTs to attain the high-impact levels of the PICRAT model when selecting and evaluating activities that utilize a technological resource. For example, when utilizing the Framework for Teaching (Danielson, 2007), teacher educators do not expect PSTs to attain the distinguished/advanced level since it is assumed that years of experience are needed in order to reach this level. Rather, the expectation is that PSTs attain either basic or proficient levels for each element of effective teaching. Similarly, it is possible that high-impact uses of technology are mostly unattainable by PSTs and are instead a product of years of technology-infused teaching experience, though more research is needed on this topic.

Liked Aspects of Activities

The themes identified during the emergent coding of Q2 (What do K-8 PSTs like about existing geometry activities that utilize a technological resource?) showed that most PSTs liked various aspects related to the content of the activity, such as the quality of mathematics content, the relevance of the context, or the variety of shapes included. However, fewer PSTs discussed aspects related to either the design of the technological resource utilized in the activity or the pedagogical implications of implementing the activity, which is what in-service secondary mathematics teachers tended to discuss (McCullough, 2018). An explanation for the imbalance among these three categories is unclear. After a thorough review of the literature, no studies were located in which the process of how K-8 PSTs determine what they liked about existing geometry activities that utilize a technological resource was examined. However, one potential explanation might be that evaluating the value of the content of an activity is easier than evaluating either characteristics of a technological resource or the pedagogical implications of implementing the activity. Another potential explanation might be that PSTs simply tend to focus on the content of an activity when conducting an evaluation. Regardless, further research on this topic is needed in order to provide additional understanding of how PSTs determine which aspects of an activity they think might be beneficial to mathematics instruction.

Disliked Aspects of Activities

The themes discovered during the analysis of Q3 (What do K-8 PSTs dislike about existing geometry activities that utilize a technological resource?) found that PSTs most frequently disliked aspects of the activity related to the pedagogical implications of implementing the activity—often noting that the activity would only be applicable in a limited

number of settings. Additionally, several PSTs disliked aspects related to the content of the activity and the design of the technological resource utilized in the activity. Similar to the analysis regarding aspects of activities that PSTs liked, no studies were found in the literature in which the process of how K-8 PSTs determine what they dislike existing geometry activities that utilize a technological resource was examined. Thus, determining the rationale as to why the largest proportion of PSTs disliked aspects related to pedagogical implications is unclear. However, PSTs' tendency to dislike aspects of the activity related to the pedagogical implications of implementing the activity aligns with prior research that highlighted PSTs' lack of confidence in their ability to integrate technology (Crompton, 2015). A focus on pedagogy when identifying disliked aspects of activities may be due to PSTs' lack of confidence in implementing an activity that utilizes a technological resource, but further research is needed to gain more understanding.

Rationale for Future Use of Activities

Findings in regard to Q4 (What characteristics of existing geometry activities that utilize a technological resource inform K-8 PSTs' interest in implementing the activity in their future classrooms?) showed that the vast majority of PSTs (93.2%) would use the geometry activity they evaluated in their future classrooms and they most frequently cited various pedagogical implications as the informing rationale for their interest. Specifically, PSTs often based their interest in future use of the activity on the potential to use the activity to either introduce content, review content, or allow students to practice newly-learned content. Several discussed the value of the mathematics content in the activity when discussing their interest in future use while a small group mentioned design aspects of the technological resource. PSTs' optimistic views

toward utilizing technology-infused activities in the future aligns with prior research showing that the majority of K-8 PSTs anticipated integrating technology into the mathematics classroom relatively frequently, such as weekly, several times per week, or daily (Meyerink & Luo, 2022). Similarly, these findings somewhat align with those of McCullough et al. (2018), as in-service secondary mathematics teachers tended to base their selection of technological resources on the technology's: (a) ease of use, (b) ability to support instruction, and (c) inclusion of interactive features. However, more research needs to be conducted in regard to why certain characteristics inform K-8 PSTs' interest in implementing an activity that utilizes a technological resource, as this is not yet addressed in the literature.

Limitations

Since the focus of this study concerned the evaluation of an existing activity that utilizes a technological resource rather than the process of locating said activity, a recommendation of browsing the GeoGebra library of resources was included in the prompt posed to PSTs (i.e., "…utilizes a technological resource [e.g., GeoGebra]"). This recommendation likely encouraged PSTs to select an existing activity located in GeoGebra's library of resources. However, it is unlikely that the inclusion of this recommendation impacted the findings of this study since the GeoGebra library contains a wide variety of existing activities. For example, the numerous GeoGebra activities evaluated by PSTs in this study were aligned with the PR, PA, IR, IA, and CA levels of the PICRAT model and had differing designs, features, characteristics, purposes, and applications. Thus, merely selecting an existing activity from GeoGebra does not ensure a particular PICRAT classification, the inclusion of desirable characteristics, or its potential for future use.

One limitation of this study is that of external validity, as this study recruited a convenience sample of PSTs from a single postsecondary institution. Due to this sampling, findings may not be generalizable to other PST populations. Additionally, since the data represent a cross section of how PSTs' evaluate geometry activities that utilize a technological resource, the findings may not align with their evaluation abilities at other points in time. Finally, while this study examined PSTs' evaluation of activities in the specific context of geometry, findings may not be generalizable to other contexts, such as other strands of mathematics.

In any study that utilizes classroom artifacts, contamination is a potential limitation in regard to internal validity. However, PSTs were instructed to independently respond to the prompt utilized for data collection and no evidence of contamination (e.g., collaboration between PSTs) was discovered by the researchers. An additional potential limitation related to internal validity is the possible impact of the two-day lesson on K-8 PSTs' evaluation of geometry activities that utilize a technological resource. However, withholding information about K-8 geometry from future K-8 teachers would be unethical, so teaching the lesson was a necessary aspect of this study.

Lastly, since the research site's protocols in response to the COVID-19 pandemic changed over time, the spring and fall course sections utilized in this study were offered in different formats. During the spring semester, courses could meet in-person but a room capacity restriction of 15 students caused the course to be offered using a hybrid format. The course used an alternating, two-group hybrid design, where half of the class attended in-person while the other half had the option to attend either synchronously via Webex or asynchronously. During the fall semester, room capacity restrictions were removed so the entire class attended in-person

for the duration of the semester. The content of the course remained the same for both semesters and no major differences in the findings between the two semesters were identified, but this potential limitation is worth noting.

Implications of Findings and Future Research

The findings of this study are promising, as most PSTs evaluated and considered the future use of an activity that utilized a technological resource in a way that aligned with the IA level of the PICRAT model. As echoed by the creators of the PICRAT model (Kimmons et al., 2020), interactive activities encourage lasting and meaningful learning (Kennewell et al., 2008) and using technology to amplify instruction can increase efficiency or improve productivity (Hughes et al., 2006). However, few PSTs evaluated and considered the future use of technology-infused activities that align with high-impact levels of the PICRAT model (e.g., CA, IT, and CT), which suggests that more ought to be done to best prepare K-8 PSTs to meaningfully integrate technology into mathematics. Additionally, while this study presented useful knowledge in regard to how K-8 PSTs evaluate existing geometry activities that utilize a technological resource and the aspects of the activity that inform their interest in future use, more research ought to be conducted to provide further explanation in regard to these findings. Lastly, while this study focused on PSTs' evaluation of geometry activities that utilize a technological research, future studies could examine other strand of mathematics, such as fraction concepts, algebraic thinking, statistics, and so forth.

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CHAPTER FOUR

K-8 PRESERVICE TEACHERS' CREATION OF GEOMETRY ACTIVITIES THAT UTILIZE A TECHNOLOGICAL RESOURCE

Contribution of Authors and Co-Authors

Manuscript in Chapter 4

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Contributions: Monte designed the study, recruited participants, collected and analyzed data, interpreted findings, and wrote the manuscript in preparation for submission.

Co-Author: Fenqjen Luo

Contributions: Fenqjen supervised the study, analyzed data, interpreted findings, and edited the manuscript in preparation for submission.

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Abstract

Research has highlighted numerous benefits of integrating technology into mathematics education but has also found that preservice teachers frequently do not feel prepared in integrate technology into their classrooms. Knowing how preservice teachers intend to integrate technology into their classrooms will inform the support that teacher preparation programs provide, as well as inform the affordances and/or limitations of available technological resources. This qualitative, ethnographic study sought to examine kindergarten through eighth-grade preservice teachers' ($N = 42$) creation of geometry activities that utilize a technological resource—focusing on the impact that the technological resource would have on instruction, preservice teachers' anticipations of how students might perform in the activity, and preservice teachers' proposed methods of providing assistance. The methodology of this study was guided by both van Hiele's model of geometric thought and the PICRAT model. Data were collected from responses to an open-ended prompt in an undergraduate mathematics methods course and analyzed using *a priori* (i.e., van Hiele and PICRAT) and emergent coding. Findings of the *a priori* coding showed that most preservice teachers created a van Hiele Level 0 activity that utilized a mathematical game in alignment with the interactive, amplification (IA) level of the PICRAT model. Additionally, emergent coding findings showed that preservice teachers more frequently focused on anticipated student challenges rather than anticipated learning outcomes, and they often planned to assist students by reviewing or demonstrating concepts. The findings also suggested that preservice teachers do not align their methods of assistance with the CRA sequence when envisioning the implementation of geometry activities that utilize a technological

resource. Lastly, implications of the findings are presented as well as recommendations for future research.

Introduction

The importance of training preservice teachers (PSTs) to effectively utilize technological resources in their future classrooms has certainly been highlighted throughout the COVID-19 pandemic. With many students in the United States attending class virtually during the pandemic (National Center for Education Statistics, 2021), teachers had to quickly learn how to recreate classroom activities that utilize technological resources rather than concrete/physical resources (Anderson & Hira, 2020). This is especially relevant to the context of kindergarten through eighth-grade (K-8) mathematics, as students' use of concrete models (e.g., base-ten blocks, connecting cubes, etc.) to explore mathematics concepts is highlighted throughout the K-8 Common Core State Standards for Mathematics (National Governors Association Center for Bests Practices & Council of Chief State School Officers, 2010). Since students are likely unable to work with concrete models while attending classes virtually (e.g., Zoom, Webex, etc.), it is crucial that teachers are prepared to utilize virtual models to replicate students' in-person learning experiences.

The use of various models in the K-8 mathematics classroom is based on the concrete, representational, abstract (CRA) sequence in which students learn about a mathematics concept by exploring different types of models. Students first use concrete models (e.g., fraction tiles or square tiles), then representational models (e.g., virtual models or drawings), and lastly abstract models (e.g., numbers and symbols) to explore a single concept. This sequence is based on Bruner and Kenney's (1965) stages of representation, which includes the enactive, iconic, and

symbolic stages. The CRA sequence has been shown to provide students with multiple benefits in relation to their conceptual understanding of mathematics concepts (Flores et al., 2018; Flores et al., 2014; Flores & Milton, 2020; Milton et al., 2019). Recent research related to the CRA sequence has adapted to the impracticality of having students experiment with concrete models while learning in an online setting and instead examines the virtual, representational, abstract (VRA) sequence (Bouck et al., 2021; Park et al., 2021; Root et al., 2021). In the VRA sequence, concrete models are removed and virtual models are no longer included in the representational stage. Thus, students first learn with virtual models, then representational models such as drawings, and lastly abstract models that use numbers and symbols. The emergence of the VRA sequence in the literature emphasizes the significance of technology integration in K-8 mathematics—especially in the context of online learning environments.

Research has shown that the use of technological resources, such as virtual manipulatives or mathematical games, in the K-8 mathematics classrooms have been beneficial to students' conceptual understanding of mathematics concepts, achievement on mathematics assessments, attitudes toward mathematics, and confidence in their abilities in mathematics (Brezovszky et al., 2019; Kiger et al., 2012; Lee & Chen, 2015; Reimer & Moyer, 2005; Sen et al., 2017; Suh & Moyer, 2007; Yuan et al., 2010). Technology integration is especially relevant in the context of geometry, as technological resources can be used to virtually model different shapes, concepts, and theorems. As noted earlier, these virtual models are extremely valuable when concrete models are unavailable for student use, such as in an online learning environment. Though the benefits of technology integration in K-8 mathematics are established in the literature, research has shown that many PSTs are not effectively prepared to integrate technology into their future

classrooms. Studies have uncovered PSTs' feelings of unpreparedness to integrate technology, lack of technology skills, lack of confidence in technology integration abilities (Crompton, 2015; Teo, 2009; Tondeur et al., 2012). Additionally, research has identified that K-8 PSTs have a self-reported lack of knowledge in relation to integrating technology into their future mathematics classrooms (Meyerink & Luo, 2022a). Thus, due to both the benefits in relation to students' learning and the feelings of PSTs identified in prior research, it is crucial that we seek more understanding in regard to PSTs' technology integration abilities.

This study sought to examine K-8 PSTs' creation of geometry activities that utilize a technological resource. More so, the researchers were interested in the impact that the technological resource would have on instruction, how PSTs anticipate their future students might perform in the activity, and the pedagogical considerations that PSTs specify are relevant in relation to the activity. Therefore, the research questions of this study were the following:

Q1. In geometry activities that utilize a technological resource created by K-8 PSTs, how would the resource impact mathematics instruction?

Q2. How do K-8 PSTs anticipate that their future students might perform in geometry activities that utilize a technological resource that they created?

Q3. What pedagogical considerations do K-8 PSTs specify when creating geometry activities that utilize a technological resource?

Theoretical Framework

This study was guided by both van Hiele's (1959/1985) model of geometric thought and Kimmons et al.'s (2020) Passive, Interactive, and Creative—Replacement, Amplification, and Transformation (PICRAT) model. The van Hiele model was utilized to situate K-8 geometry

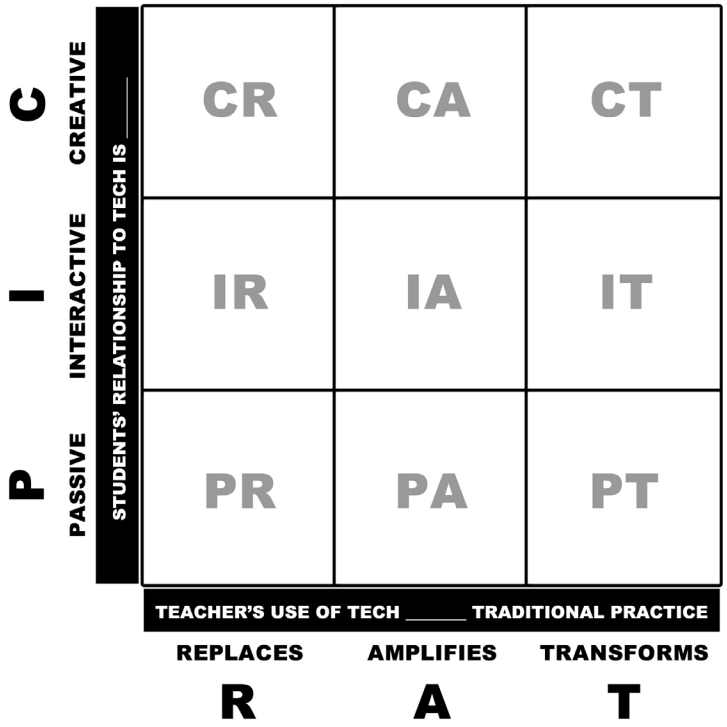
content while the PICRAT model was employed as a lens for considering the impact of technology integration on mathematics instruction.

This study applied van Hiele's (1959/1984) model of geometric thought as a lens to understand geometry activities created by K-8 PSTs. In his theory, van Hiele outlined five distinct, sequential levels through which students' understanding of geometry progresses. At level 0 (visualization), students identify shapes based on their visual characteristics (e.g., "looks like a square"). Students at level 1 (analysis) identify individual shapes by their specific properties (e.g., equal side lengths, opposite sides are parallel, etc.). At level 2 (informal deduction), students compare different shapes based on their properties and examine the interrelationships between shapes (e.g., a square is also a rhombus, a rectangle, and a parallelogram). Students at level 3 (formal deduction) are able to formally prove the properties of a shape or prove the classification of a shape based on a given set of properties. At level 4 (rigor), students understand the importance of axioms, postulates and theorems on a geometric system, as well as understand and explore non-Euclidean geometric systems (e.g., hyperbolic, elliptic, taxicab, etc.).

While van Hiele's model includes five levels, only the first three (levels 0-2) are relevant to the context of this study. This can be observed by viewing the kindergarten through twelve grade (K-12) geometry standards outlined in the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Standards that align with levels 0-2 are located in K-8 while those aligned with level 3 are highlighted in the high school geometry standards. Additionally, level 4 is not included in the K-12 standards as the study of non-Euclidean geometries (e.g., elliptic,

hyperbolic, taxi-cab, etc.) generally does not occur until students' postsecondary education. The van Hiele model influenced the overall design of this study in several ways. Namely, the prompt utilized for data collection was aligned with age-appropriate levels for K-8 students and the van Hiele model was employed when analyzing data as well as interpreting the findings of the study. Additionally, the application of the van Hiele model helps to situate the context of this study in relation to K-8 geometry content.

Figure 4.1. The PICRAT Matrix



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

Kimmons and colleagues' (2020) PICRAT model was utilized as a theoretical lens in this study to analyze technology integration. Viewing K-8 PSTs' creation of geometry activities that

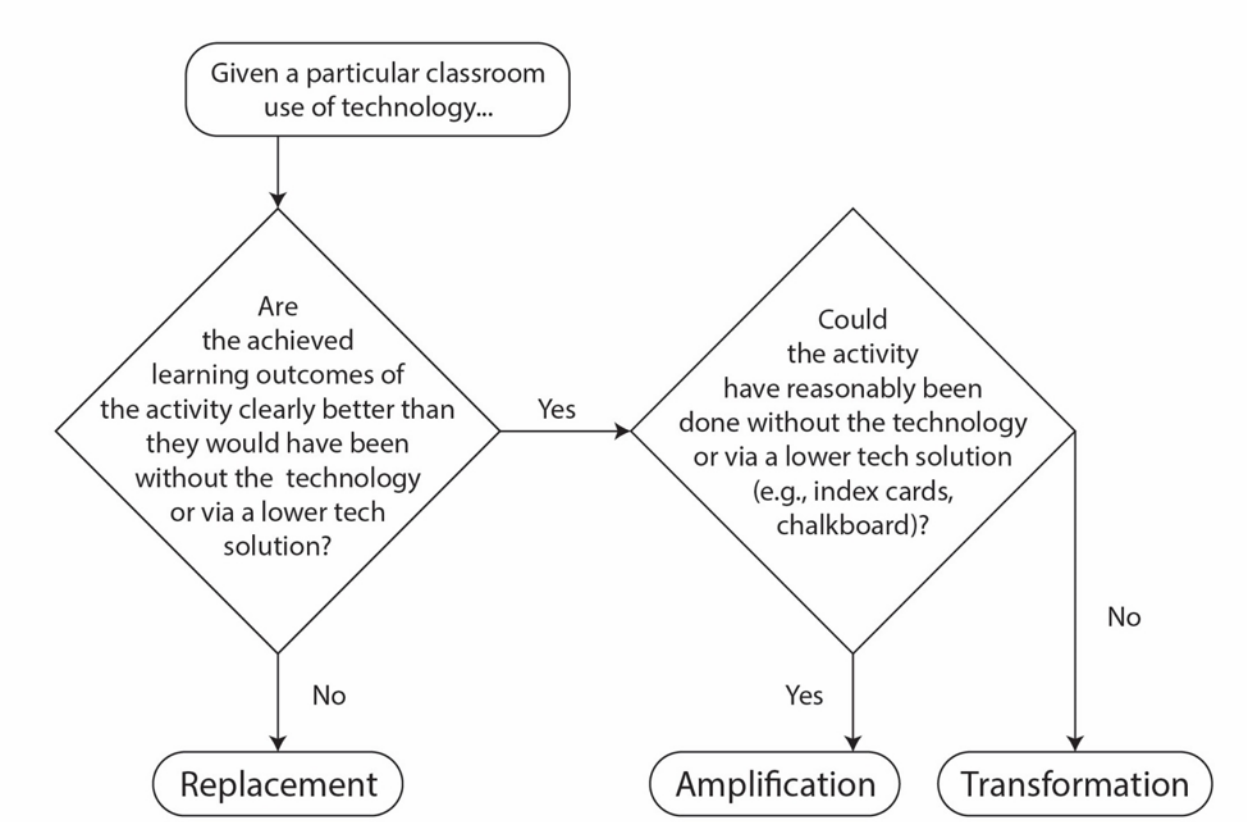
utilized a technological resource through the lens of the PICRAT model allowed the researchers to examine technology's impact on mathematics instruction in respect to both students' relationship to technology and teachers' pedagogical practices. As shown in Figure 4.1, the PICRAT model is organized into a hierarchical matrix with nine distinct levels that categorize the impact of technology on instruction.

The vertical axis of the PICRAT model (the PIC portion) categorizes the way in which students use a technological resource during instruction. This portion is divided into three distinct levels: passive learning, interactive learning, and creative learning. At the passive level, students are passively receiving content via a technological resource—such as watching a YouTube video or reading text on a website. While passive modes of learning are essential in the educational setting, they are generally not sufficient learning skills for students (Kimmons et al., 2020). The next level—interactive—has been associated with learning that is more lasting and impactful (Kennewell et al., 2008). At this level, students use a technological resource for exploration, experimentation, collaboration, and other active behaviors such as manipulating virtual models or playing educational games. However, Kimmons and colleagues (2020) noted that technology use is still somewhat limited at the interactive level, as "learning is largely structured by the technology rather than by the student" (p. 186). At the creative level, students are utilizing technology to create learning artifacts, such as using a dynamic geometry software to create models of three-dimensional shapes or using a data visualization software to create scatter plots with lines of best fit. As noted by Papert and Harel (1991), lasting, meaningful learning best occurs when students are able to employ their knowledge of concepts and skills by creating artifacts to solve problems. Kimmons et al. (2020) suggested that viewing technology

use in respect to students' relationship with technology helps to prevent technocentric thinking—or "ascribing educational value to the technology itself" (p. 187)—and encourages teachers to consider how students might use technological resources in their classrooms.

The horizontal axis of the PICRAT model (the RAT portion) categorizes technology use in relation to how a technological resource impacts teachers' pedagogical practices. This portion was originally developed by Hughes and colleagues' (2006) and is divided into three separate levels: replacement, amplification, and transformation. At the replacement level, technology use replaces previous practices without noticeably improving students' learning outcomes, such as using a virtual version of base-ten blocks rather than physical base-ten blocks. While technology integration at the replacement level may encourage some benefits (e.g., efficiency, engagement), neither students' learning nor teachers' practices are significantly impacted. The second level—amplification—is highlighted by a clear improvement in students' learning outcomes due to the use of technology. Examples of technology use categorized as amplification include students' use of games that provide instant feedback or their use of digital devices to gather data. While impacts to students' learning outcomes occur at this level, teachers' pedagogical practices are enhanced but not drastically influenced. At the transformation level, the use of technology has a significant impact on both students' learning outcomes and teachers' pedagogical practices—enabling practices that would be inconceivable or impractical without the use of technology. Examples of technology use at this level include using: (a) dynamic models to informally prove geometry theorems, (b) data visualization software to simulate and analyze data, or (c) a video conferencing software to interview an expert. Kimmons and colleagues presented a flowchart to supplement their description of the RAT portion of the PICRAT model as shown in Figure 4.2.

Figure 4.2. PICRAT Flowchart for the RAT



Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

The influence of the PICRAT model on this study is evident in relation to multiple aspects of its design. The prompt utilized for data collection was designed in a way that would provide information on both students' and teachers' use of technology within the activities created by PSTs. Additionally, a portion of the data analysis was guided by the PICRAT model as it was applied as an *a priori* codebook. Lastly, when interpreting the findings of this study, the PICRAT model was utilized as a lens for discussing the findings and their implications.

Methodology

In this qualitative study, a social constructivist paradigm was employed to seek an understanding of K-8 PSTs' creation of geometry activities that utilize a technological resource. The application of social constructivism is evident in the design of this study, as this paradigm relies on the views and opinions of participants when forming an understanding of reality (Creswell & Poth, 2017). Within this lens, an ethnographic approach was utilized to analyze the culture of K-8 PSTs—specifically in the context of creating geometry activities that utilize a technological resource. The definition of *culture* used in this study aligns with that of Mills and Gay (2018): "Culture is a set of attitudes, values, concepts, beliefs, and practices shared by members of a group" (p. 379). Therefore, to align with this social constructivist, ethnographic design, this study collected PSTs' responses and interpreted the findings to describe the culture of PSTs' creation of geometry activities that utilize a virtual resource. The research design of this study does not include the common ethnographic practice of longitudinal data collection. However, the researchers categorized this study as an ethnography due to their roles as course instructors (i.e., continuous interactions with participants) and the study's goal of describing PSTs' shared culture in the context of creating K-8 geometry activities that utilize a technological resource.

Researcher Positionality

When operating in a social constructivist paradigm, researchers must situate themselves in relation to the context of this study—primarily due to the assumption within this paradigm that reality is co-constructed between the researchers and the researched (Creswell & Poth, 2017). At the time of this writing, the first author is a mathematics education doctoral candidate and

instructor of K-8 Math Methods. His primary research interest is PSTs' attitudes toward and preparation to integrate technology into the mathematics classroom. The second author is an associate professor of mathematics education and also teaches K-8 Math Methods—having taught undergraduate and graduate courses at the research site since 2010. Due to their roles as instructors, the researchers recognized the potential for power/status differentials between themselves and their students (i.e., the participants), which may have had an impact on participation or PSTs' responses to the prompt utilized for data collection. The researchers were mindful of this potential and reflected on their personal biases, beliefs, and experiences with PSTs when recruiting participants, collecting/analyzing data, and interpreting the findings.

Context, Population, and Sample

This study was conducted at large postsecondary institution in the Northwest region of the United States and approved by its Institutional Review Board. K-8 PSTs ($N = 42$) enrolled in an undergraduate mathematics methods course (i.e., K-8 Math Methods) in both the spring and fall semesters of 2021 were recruited for this study. Participants were enrolled in an elementary education program that led to initial teaching licensure for grades K-8 and were juniors and seniors academically (i.e., final or penultimate years of undergraduate program). Several participants were completing field experiences during the semester in which they were enrolled in K-8 Math Methods and some would be student teaching in the semester following the course. Therefore, the population of this study was K-8 PSTs enrolled in K-8 Math Methods and majoring in elementary education at the research site.

For both the spring and fall sections of K-8 Math Methods, PSTs participated in a two-day lesson (two 75-minute periods) during the fifteenth week of each semester on learning

theories, pedagogical considerations, and mathematics content relevant to K-8 geometry. The content of the lesson was informed by Van de Walle and colleagues' (2018) chapter on geometric thinking and geometric concepts, including topics such as: (a) van Hiele's (1959/1984) levels of geometric thought and its impact on geometry curricula, (b) the CRA sequence (Bruner & Kenney, 1965) and its application to geometry concepts, and (c) K-8 geometry content—especially shapes and properties due to the emphasis of this topic as seen in the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). During the two-day lesson, PSTs completed several in-class activities related to each of the three primary topics and gained experience using a dynamic geometry software (i.e., GeoGebra) to model several geometry concepts.

Data Collection

Data were collected following the two-day lesson on K-8 geometry. Notably, data collection occurred in April and November of 2021 during the COVID-19 pandemic. The creation of the prompt used for data collection was informed by both the van Hiele and PICRAT models. As the focus of this study was PSTs' creation of geometry activities that utilize a technological resource, PSTs were asked to respond to the following prompt:

> Design and describe a short two-dimensional (2D) or three-dimensional (3D) sorting or classifying activity that utilizes a technological resource that might encourage students to transition from van Hiele's Level 0 (visualization) to Level 1 (analysis). Additionally, include: (a) prompts for students, (b) anticipated student learning outcomes and/or challenges, and (c) methods of assisting students and/or addressing challenges.

Responses were submitted to the researchers through a learning management system and downloaded as individual files. The researchers then organized PSTs' responses into a Microsoft

Excel spreadsheet in preparation for data analysis. Additionally, PSTs' names were redacted from the spreadsheet and replaced with identification numbers to ensure confidentiality.

Data Analysis

The researchers utilized the PICRAT model as an *a priori* codebook to examine the first research question. Each researcher independently coded PSTs' responses as passive, interactive, or creative (PIC) and replacement, amplification, or transformation (RAT). For occasions where multiple levels were arguably applicable to a PST's described use of technology, the researchers selected the level that aligned with the activity's most prominent use of technology. Following their initial coding, the researchers met to compare, discuss, assess the interrater reliability (IRR), and make changes as deemed necessary. Additionally, the researchers utilized the same *a priori* coding process when coding PSTs' activities in alignment with the van Hiele model to describe the types of sorting or classifying activities PSTs created. Emergent coding was employed to examine the second and third research questions as well as to provide a description of the types of technological resources that were showcased in PSTs' activities. The emergent coding process was based on the theme-identifying strategy of repetition, in which themes are identified on the basis of the frequency at which they occur and reoccur (Ryan & Bernard, 2003). The procedures for emergent coding used in this study were informed by the recommendations of Creswell and Poth (2017). The researchers first established a coding platform (i.e., Microsoft Excel spreadsheet) and cooperatively created a preliminary codebook relative to each research question. Each researcher then individually applied the preliminary codebooks to each PST's response. Following this initial coding, the researchers compared and discussed their coding, assessed the IRR, and made any final changes as deemed necessary. The IRR in this study is

represented as percent agreement (i.e., the percentage of codes that were identical for both researchers) as recommended by Creswell and Poth.

Methods of Achieving Validity

Creswell and Poth (2017) highlighted several constructs related to validity that can be increased by employing various qualitative methods to a study. We sought to increase the dependability of this study be presenting detailed descriptions of our research procedures so that they might be easily understood, replicated, and/or critiqued. The confirmability of our findings were improved through the inclusion of verbatim responses from PSTs and a rich description of the data collection and analysis procedures that were utilized. We established the appropriate criteria for transferability of the findings by clearly describing the research site, population, and sample in this study. We also enhanced the authenticity of this study by positioning ourselves in relation to the contexts of technology integration and K-8 mathematics. Finally, we sought to increase the reliability of the presented findings by employing multiple coders, assessing the IRR in comparison to recommendations in the literature, and making use of peer review.

Results

A total of 53 PSTs were recruited for this study and 22 from each semester ($N = 44$, 83.0%) consented that their responses may be analyzed for research purposes. Missing data was a minor issue in this study, as two PSTs did not integrate technology into their activity and instead utilized physical manipulatives. Additionally, two PSTs did not provide responses in regard to anticipated student learning outcomes or challenges and one PSTs did not discuss methods of assisting students and/or addressing challenges. The two PSTs who did not use

technology were excluded from this study, resulting in a final sample of $N = 42$. PSTs who were missing just one response were only excluded from the associated analysis (i.e., Q2 and Q3) since they adequately responded to other portions of the prompt. Analyses on the basis of demographic factors (e.g., gender, race/ethnicity, year in program, etc.) were not explored due to the lack of variance in these factors in the study sample, as most participants were White females in their third or fourth year of study.

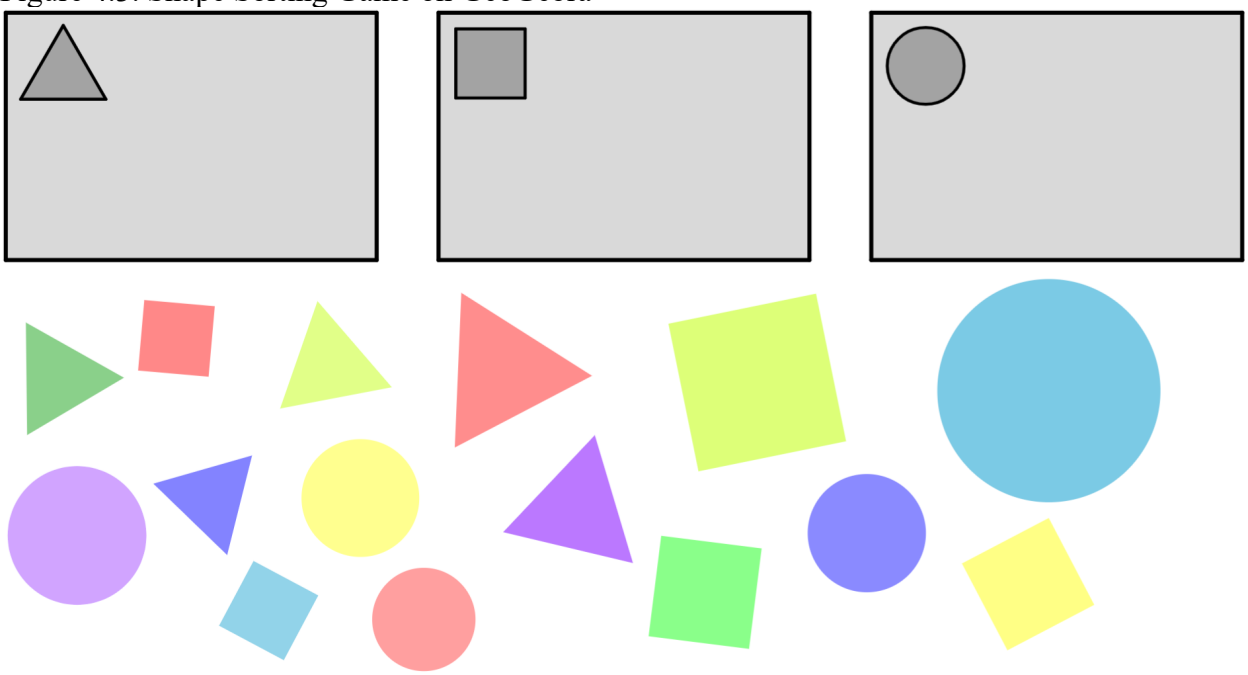
The researchers assessed the IRR of both the *a priori* and emergent coding after they had each individually coded all the data. *A priori* coding in alignment with both the PICRAT and van Hiele models proved to be very reliable. The researchers attained an IRR of 95.2% (40/42) for the PIC portion of the PICRAT model, an IRR of 92.9% (39/42) for the RAT portion of the model, and an IRR of 88.1% (37/42) for the PICRAT model overall. Additionally, an IRR of 97.6% (41/42) was attained in regard to the van Hiele model. For the emergent coding, the researchers attained an IRR of 97.6% (41/42) when coding the types of technological resources utilized in activities created by PSTs, an IRR of 89.3% (25/28) when coding PSTs' anticipated student learning outcomes, an IRR of 89.7% (35/39) when coding PSTs' anticipated student challenges, and an IRR of 87.8% (36/41) when coding PSTs' proposed methods of assisting students and/or addressing challenges. Overall, the emergent coding in this study produced a mean weighted IRR of 91.3% (137/150). It is worth mentioning that—due to missing responses from PSTs—the sample size varies on some of the emergent coding analyses. Due to the observed IRRs in this study, both the *a priori* and emergent coding is acceptable and reliable as it exceeds Creswell and Poth's (2017) recommended minimum IRR of 80%.

Emergent coding was used to categorize the different types of technological resources that PSTs (n = 42) integrated into their K-8 geometry activities. The analysis found that PSTs used four distinct types of technological resources when creating activities, as shown in Table 4.1. The largest proportion of PSTs (n = 27, 64.3%) utilized a mathematical game in their created activity. Other types of technological resources integrated into PSTs' activities included a virtual manipulative (n = 13, 31.0%), a lesson located on a website (n = 1, 2.4%), and an instructional mathematics video (n = 1, 2.4%). Many of the mathematical games utilized in PSTs' activities asked students to sort shapes into categories based on their visual characteristics, such as the GeoGebra game shown in Figure 4.3.

Table 4.1. Type of Technological Resource Utilized in Activities Created by PSTs

Resource Type	*n*	Examples
Mathematical game	27	• Sorting geometric shapes (https://www.geogebra.org/m/wHnByPks) • Two- and three-dimensional shape sort (https://www.education.com/game/2d-3d-shapes/) • Venn diagram shape sorter (http://shodor.org/interactivate/activities/ShapeSorter/)
Virtual manipulative	13	• Virtual geoboard (https://www.mathplayground.com/geoboard.html) • Virtual pattern blocks (https://www.didax.com/apps/pattern-blocks/) • Interactive models of shapes with properties (https://www.geogebra.org/m/fgswz6b7)
Lesson	1	• Curriculum for similar triangles (https://www.ck12.org/geometry/similarity/lesson/Triangle-Identification-as-Similar-Congruent-or-Neither-MSM6/)
Video	1	• Instructional video on classifying shapes (https://www.khanacademy.org/math/early-math/cc-early-math-geometry-topic/cc-early-math-properties-shapes/v/sides-corners)

Figure 4.3. Shape Sorting Game on GeoGebra



Note. From "Sort the Geometric Figures," by GeoGebra Team German & GeoGebra Translation Team German, 2022, *GeoGebra* (https://www.geogebra.org/m/wHnByPks#material/bgY4rBep). CC BY-NC.

PSTs were prompted to create a sorting or classifying activity that could be implemented with K-8 students whose geometric thought aligned with level 0 (creating groups based on visual characteristics) and were progressing toward a level 1 understanding (examining specific properties of shapes). The van Hiele (1959/1984) model was utilized as an *a priori* codebook to determine whether PSTs' activities aligned with the levels requested in the prompt. Most PSTs (n = 34, 81.0%) created an activity that was well-aligned with level 0, as the focus of these activities was on students' ability to create groups of shapes based on visual similarities. The other PSTs (n = 8, 19.0%) created activities that were more aligned with level 1, as students would be asked to learn about and examine properties of specific shapes rather than grouping shapes solely based on visual characteristics. None of the activities created by PSTs aligned with

levels 2-4 of the van Hiele model. Examples of activities created by PSTs viewed through the lens of the van Hiele model are shown in Table 4.2.

Table 4.2. Activities Through the Lens of the van Hiele Model

van Hiele Level	*n*	Examples
0: Visualization	34	• Sorting multiple shapes based on visual characteristics (https://www.geogebra.org/m/wHnByPks#material/bgY4rBep)
1: Analysis	8	• Examining properties of individual shapes (https://www.geogebra.org/m/fgswz6b7)

Impact of Technological Resources on Mathematics Instruction

PSTs' responses (n = 42) were coded through the lens of the PICRAT model to address the first research question (In geometry activities that utilize a technological resource created by K-8 PSTs, how would the resource impact mathematics instruction?). Each researcher assessed the use of technology in terms of the affordances of the technological resources as well as PSTs' proposed use in the classroom and coded each response as either passive, interactive, or creative (PIC) and either replacement, amplification, or transformation (RAT). Frequencies and examples of PSTs' responses that aligned with each PICRAT level observed in this study are shown in Table 4.3. None of the activities created by PSTs utilized technology in a way that aligned with the PT (passive, transformation); IT (interactive, transformation); CA (creative, amplification); or CT (creative, transformation) levels of the PICRAT model in this study.

Table 4.3. Activities Through the Lens of the PICRAT Model

PICRAT Level	*n*	Examples
PR	3	• Watching a video on shape classification (https://www.khanacademy.org/math/early-math/cc-early-math-geometry-topic/cc-early-math-properties-shapes/v/sides-corners)
PA	6	• Completing a non-interactive quiz that provides instant feedback (https://www.mathgames.com/skill/1.8-identify-same-shapes)
IR	7	• Sorting shapes into categories using virtual pattern blocks (https://toytheater.com/pattern-blocks/) • Composing/decomposing shapes with an interactive tangram puzzle (https://www.geogebra.org/m/zrGERP88)
IA	23	• Playing interactive games that provide instant feedback (https://www.geogebra.org/m/wHnByPks#material/bgY4rBep or https://www.geogebra.org/m/wHnByPks#material/BYSURwXc)
CR	3	• Creating shapes with a virtual geoboard (https://www.didax.com/apps/geoboard/)

Overall, most PSTs (*n* = 23, 54.8%) created an activity that utilized technology in a way that aligned with the IA (interactive, amplification) level of the PICRAT model. Many of the activities coded as IA asked students to drag 2D or 3D geometric shapes of varying size and orientation into one of several categories (e.g., squares, triangles, cubes, pyramids, etc.) using a mathematical game. These activities fit the criteria to be coded as interactive since students would need to interact with the resource (i.e., dragging shapes) in order to engage in the mathematics content. The rationale for coding these activities as amplification revolved around their inclusion of instant feedback. This feedback would likely improve students' learning outcomes but would not likely impact teachers' pedagogical practices considerably, as a similar activity could be implemented without the use of technology. Seven other PSTs (16.7%) created activities in which students would engage in interactive learning, but their activity would not likely impact either students' learning outcomes or teachers' pedagogy. Thus, these activities

were aligned with the IR (interactive, replacement) level of the PICRAT model. Activities frequently asked students to use virtual manipulatives (i.e., pattern blocks) to sort shapes based on their visual characteristics. While these activities fostered interactive learning, the technological resources did not include features that would clearly benefit students' learning outcomes (e.g., instant feedback, integrated differentiation, etc.). Thus, these activities were coded as replacement since students' learning would not likely significantly differ if a physical resource were utilized in the place of the technological resource.

Nine PSTs created a geometry activity in which students were using technology to engage in passive learning, with six (14.3%) aligning with the PA (passive, amplification) level of the PICRAT model and three (7.1%) aligning with the PR (passive, replacement) level. In these activities, students could engage with the mathematics content without meaningfully interacting with the technology or using the technological resource to create learning artifacts. Instead, passive forms of learning (e.g., reading, observing, etc.) would primarily be required of students in these activities. Activities coded as PA utilized non-interactive mathematical games that would quiz students about the classification of various shapes. These games likely improved students' learning outcomes due to the inclusion of instant feedback, so they were coded as amplification. The activities coded as PR included the use of an instructional mathematics video, a website with explanations of mathematics content (e.g., text and images), and pre-created shapes displayed with a virtual geoboard. In these activities, the use of the technological resource would not likely have an impact on students' learning when compared to an activity that did not integrate technology, so they were coded as replacement.

Just three PSTs (7.1%) created an activity that aligned with the CR (creative, replacement) level of the PICRAT model. In all of these activities, students would be asked to use a virtual geoboard to create their own shapes and then sort these shapes into groups based on their similarities. This use of technology aligned with the creative level of the PICRAT model because students would use the virtual geoboards to create their own shapes. However, these activities were coded as replacement since they could feasibly be implemented with a physical geoboard—likely without significantly impacting students' learning outcomes or teachers' pedagogical practices.

Anticipated Student Performance

The second research question (How do K-8 PSTs anticipate that their future students might perform in geometry activities that utilize a technological resource that they created?) was examined by analyzing PSTs' responses to the portion of the prompt that asked for anticipated student learning outcomes and/or challenges. Two PSTs did not provide a response to this portion of the prompt, so they were excluded from this analysis which produced a sample size of $n = 40$. Additionally, nearly all of the PSTs ($n = 39$, 97.5%) discussed anticipated challenges that might occur during the activity while a smaller group ($n = 28$, 70.0%) provided anticipated student learning outcomes. The emergent coding for anticipated student learning outcomes uncovered four themes: (a) sorting shapes by similarities, (b) demonstrating knowledge of properties, (c) comparing 2D and 3D shapes, and (d) composing shapes using smaller shapes. For anticipated challenges, emergent coding identified six themes: (a) confusing the properties of various shapes, (b) focusing on other shape characteristics, (c) not understanding the difference between 2D and 3D shapes, (d) not understanding the criteria for sorting, (e) struggling to use the

technological resource, and (f) not being familiar with terminology. Frequencies and examples of PSTs' responses that informed themes each observed theme related to anticipated student learning outcomes and challenges are shown in Table 4.4 and Table 4.5. In both of these analyses, each PST's response could be coded as multiple themes, so the sums of frequencies in Table 4.4 and Table 4.5 are greater than the sample size.

Table 4.4. Anticipated Student Learning Outcomes

Theme	*n*	PSTs' Responses
Sort shapes by similarities	17	• Students will respond by placing shapes in the categories provided by the teacher or in categories they've created themselves depending on how the teacher wants to approach the activity • Students should be able to accurately group all like shapes • Students should be able to correctly identify the shapes provided by their names, and group them in their correct shape categories
Demonstrate knowledge of properties	8	• Anticipated student solutions include students making an isosceles and obtuse triangle rather than a right triangle • Students should be able to group shapes in the following categories: (a) Opposite sides "go the same way"—parallelograms (b) Three sides—triangles (c) Shapes with a "square corner"—right angle • Students could sort based upon parallel sides, right angles, etc.
Compare 2D and 3D shapes	7	• Students will be asked to…sort the different shapes by naming them and saying whether they are 2D or 3D • Students might say something like, "We put these shapes into one group because they look the same, one is just flat" • Hopefully, students will start to see that 2D shapes are flat and 3D shapes are not flat (or have volume to them)
Compose shapes	3	• Students will likely construct simple polygons with 3-4 sides, and will classify them as such, with some possible 5-sided figures being included

Table 4.5. Anticipated Student Challenges

Theme	*n*	PSTs' Responses
Properties of shapes	12	• Students could have trouble regarding the differences between squares and rectangles • Students may struggle with understanding the difference between squares, rectangles, rhombuses, and parallelograms—they all have four sides, so they will need to realize what makes them different • I think students may struggle with the fact that a circle has 0 sides and 0 corners
Other shape characteristics	8	• Students may struggle with the idea of the shapes being sorted into the same category if they are different sizes or colors • Students may think that the dice has circles on it so it may be in the circle category • One thing that might be challenging for students is when the shapes have different orientations, sizes, or colors
Difference between 2D and 3D shapes	8	• A potential misconception a student could have is thinking that the 2D and 3D shapes that are the same will have all of the same characteristics, such as a 2D and 3D square • Students might not understand what makes the difference between 2D and 3D shapes • I think students may get confused on the initial concept of 3D
Criteria for sorting	5	• Students may have struggles when it comes to grouping their [created] shapes with others • Some students may have troubles sorting shapes according to their visual properties • Students may struggle to categorize the shapes into two separate categories by identifying key features
Technological resource	5	• Students might have trouble making their new shape [due to using] GeoGebra • The virtual tool may get a bit confusing since most of the lengths are in decimals • Students may be confused on how to play the game
Terminology	5	• Students may be unclear on what each solid is called • Some students may struggle with recognizing the different names or mixing up the names of the shapes • [Students] may have a hard time remembering the name of some shapes

Of the 28 PSTs who provided anticipated student learning outcomes when describing how students might perform in the activity they created, most (n = 17, 60.7%) discussed ways in which students might sort shapes based on their similarities. Generally, activities had pre-determined criteria for grouping as many utilized a technological resource with specific categories (e.g., squares, triangles, and circles), but a few activities allowed students to create their own grouping criteria. Eight PSTs (28.6%) discussed how students might demonstrate their knowledge of properties in their solutions, such as sorting shapes based on properties (e.g., parallel sides, right angles, etc.) or creating shapes with certain properties (e.g., isosceles triangle, obtuse triangle, etc.). Several other PSTs (n = 7, 25.0%) suggested that students' learning outcomes might highlight a comparison between 2D and 3D shapes, such as discussing the difference between "flat" or "solid" shapes. Lastly, three PSTs (10.7%) focused on how students would compose shapes from smaller shapes during the activity rather than focusing on sorting criteria or properties when discussing anticipated student learning outcomes.

In comparison to PSTs' anticipated student learning outcomes, more PSTs (n = 39) discussed anticipated challenges that might arise when implementing the activities that they created. The most frequently discussed challenge discussed by PSTs (n = 12, 30.8%) were related to the properties of shapes. Often, PSTs anticipated that students would struggle to understand the difference between various quadrilaterals (e.g., squares, rectangles, rhombi, and parallelograms) or understand how side lengths and angle measures impact the classification of a shape. Another challenge reported by PSTs (n = 8, 20.5%) related to students focusing on characteristics of shapes that were not relevant to how they are classified. Examples of these characteristics as identified by PSTs included the shape's orientation, size, and color. Eight PSTs

(20.5%) anticipated that students might have challenges regarding the difference between 2D shapes and 3D shapes or the understanding that 3D shapes are composed of multiple 2D shapes. For example, one PST thought students might think that a square and a cube could be considered as the same shape (e.g., "a 2D and 3D square") due to their similarities. Five PSTs (12.8%) thought challenges might arise in relation to the criteria for sorting shapes based on their similarities. PSTs suggested that some students might struggle with this sorting because they could have challenges when visually identifying characteristics of shapes (e.g., equal side lengths, opposite sides are parallel, etc.). A small group of PSTs (n = 5, 12.8%) anticipated that students' challenges would be related to the use of technology in the activity. Most comments related to this anticipated challenge related to students being confused with how to use the technological resource due to their lack of prior use. Lastly, five PSTs (12.8%) thought that students might have challenges due to their unfamiliarity with the terminology that is used when studying geometric shapes. This included both students' lack of knowledge of terms and their potential to mix up names of shapes.

Proposed Methods of Assistance

To analyze the third research question (What pedagogical considerations do K-8 PSTs specify when creating geometry activities that utilize a technological resource?), PSTs' responses to the portion of the prompt that asked for methods of assisting students and/or addressing challenges were examined. One PST did not provide a response to this portion of the prompt and was excluded from analysis, resulting in a sample of n = 41. The emergent coding identified seven themes: (a) reviewing concepts with students, (b) demonstrating concepts, (c) providing students with additional resources, (d) additional questioning, (e) leading a whole-class

discussion, (f) encouraging collaboration, and (g) using a physical model. Frequencies and examples of PSTs' responses that informed each observed theme are shown in Table 4.6. Since each PST's response could potentially be coded as multiple themes, the sum of frequencies in Table 4.6 is greater than the sample size.

The method for assisting students and/or addressing challenges most frequently discussed by PSTs (n = 14, 34.1%) was to review relevant concepts with the students. Often these reviews included additional information about visual characteristics of shapes, properties of shapes, or how to sort the shapes into groups. Other PSTs (n = 9, 22.0%) stated that they would assist students by providing some sort of demonstration, such as showing how to manipulate and/or sort various shapes. Eight PSTs (19.5%) planned to provide additional resources in order to assist students and/or address challenges. Examples of these additional resources included lists of various definitions (e.g., 2D shape, 3D shape, square, rectangle, parallelogram, etc.); a taxonomical guide for classifying polygons based on their properties; and a video clip of a 3D movie to highlight the difference between 2D and 3D shapes. Several PSTs (n = 6, 14.6%) noted that they would assist students by posing additional prompts/questions, such as, "Let's see if your idea is true for all squares" or "What does the shape look like to you?" Five PSTs (12.2%) planned to assist students and/or address challenges by leading a whole-class discussion to encourage further examination of the concept in question. A small group of PSTs (n = 4, 9.8%) suggested that they would encourage collaboration when students needed assistance, such as working in small groups or asking a peer for help. The final theme—using a physical model—was noted as a method for assisting students and/or addressing challenges by four PSTs (9.8%).

In these responses, PSTs stated that they would either demonstrate concepts with a physical model or provide students with a physical version of the virtual model being used in the activity.

Table 4.6. Proposed Methods of Assisting Students

Theme	*n*	PSTs' Responses
Review concepts	14	• In order to assist the students, we will go over the main shape groups and do an initial group sorting activity • [I would] make sure to do a review before this activity to go over the various types of geometric shapes and their names and classifications • I will assist students…by reviewing properties and characteristics of shapes
Demonstrate concepts	9	• The teacher can model sorting a few of the shapes on the projector to give students an example • It will be important to show how to manipulate shapes as a class • I could demonstrate how to [set up the technological resource] on the board while students are at their desks following along
Provide additional resources	8	• I would have the definitions of 3D and 2D up [on the whiteboard] so [students] can have something to refer to • I will give struggling students a taxonomical guide to classify polygons based on the number of sides, sizes of angles, etc. • Showing a clip of a 3D movie…would be helpful
Additional questioning	6	• I will prompt student thinking with, "Let's see if your idea is true for all squares" • [I would use] prompting questions such as, "What does the shape look like to you?"
Lead whole-class discussion	5	• I could…lead the class in a discussion of how we know which is which [e.g., squares versus rectangles] • The teacher could have a discussion with students about how to make more mathematical categories
Encourage collaboration	4	• [In] this activity, you could start out as a group and then have individual students practice with the shapes • Students unable to complete the activity alone could be placed in a small group
Use a physical model	4	• The students unable to complete [the activity] will use a physical model instead of an online one • I think showing physical models would be extremely helpful

Discussion

The findings of this study were consistent with those in prior research that highlighted PSTs' intentions to integrate technology in ways that align with the IA level of the PICRAT model, as well as PSTs' tendency to utilize mathematical games (Meyerink & Luo, 2022a; Meyerink & Luo, 2022b). Additionally, this study provided insight on several pedagogical factors related to technology integration in K-8 mathematics, including how PSTs anticipate students might perform in activities that utilize a technological resource and how PSTs plan to assist students during implementation. Lastly, this study further established the reliability and utility of using the PICRAT model to assess K-8 PSTs' relationship with technology integration in the context of mathematics. However, the authors reiterate their light critique of the PICRAT model and suggest that future studies use the PICRAT model to assess the impact of technology on instruction over time—potentially as weighted observations—rather than as a summative snapshot due to possibility that multiple PICRAT levels may occur within a single activity or lesson (Meyerink & Luo, 2022a).

Impact of Technological Resources on Mathematics Instruction

When utilizing the PICRAT model as an *a priori* codebook to examine Q1 (In geometry activities that utilize a technological resource created by K-8 PSTs, how would the resource impact mathematics instruction?), findings showed that most PSTs created activities that utilized a technological resource in alignment with either the IA level of the PICRAT model (n = 23, 54.8%) or the IR level (n = 7, 16.7%). Less frequently, activities used technology in ways that aligned with the PA (n = 6, 14.3%), PR (n = 3, 7.1%), or CR (n = 3, 7.1%) levels of the PICRAT model. Notably, no PSTs created an activity that used technology in a way that aligned with the

high-impact levels located in the upper right corners of the PICRAT model (e.g., CA, IT, and CT). This tendency to integrate technology in alignment with the interactive and/or amplification level of the PICRAT model aligns with prior research on both PSTs (Meyerink & Luo, 2022a; Meyerink & Luo, 2022b) and in-service teachers (Thomas & Edson, 2019). However, it seems that K-8 PSTs are more likely to anticipate integrating technology in a more impactful way when locating and evaluating an existing activity when compared to creating an activity. Meyerink and Luo (2022a) found that 65.9% of existing geometry activities evaluated by K-8 PSTs aligned with the IA level of the PICRAT model—compared to just 54.6% of geometry activities created by PSTs in this study. Additionally, a greater proportion of activities were coded as IR in this study (16.7%) compared to Meyerink and Luo's (2022a) examination of existing activities evaluated by K-8 PSTs (11.4%). PSTs' tendency to create activities aligned with the IA level of the PICRAT model is promising, as these activities will likely encourage lasting, meaningful learning and allow teachers to improve students' learning outcomes (Hughes et al., 2006; Kennewell et al., 2008). However, it appears that further research is warranted to discover methods that might increase K-8 PSTs' abilities to integrate technology into mathematics in more impactful ways, especially in regard to the creation of activities.

There are several potential factors that might help explain the lack of activities that align with high-impact levels of the PICRAT model (e.g., CA, IT, CT) in this study. One potential factor relates to PSTs' technology integration abilities. Meyerink and Luo (2022b) found that over one third of the PSTs in their sample self-reported a lack of knowledge regarding technology integration into K-8 mathematics. Thus, it is possible that PSTs simply do not possess the ability to create activities that align with high-impact levels of the PICRAT model

and, therefore, design activities that utilize technology in a way that translates to a lesser impact on mathematics instruction. This potential explanation was noted by Meyerink and Luo (2022a) when considering the expectations for PSTs in relation to the Framework for Teaching (Danielson, 2007). Since PSTs are not expected to attain the distinguished/advanced level regarding various elements of effective teaching, it is similarly possible that teacher educators should not expect high-impact technology integration from PSTs as the CA, IT, and CT levels of the PICRAT model may be a product of years of technology integration experience. Another potential factor relates to the ability of the technological resource itself. For example, many of the technological resources used by PSTs in this study were mathematical games. Since these games have a somewhat restrictive environment, the potential to have students use the game to engage in creative learning, for example, is not possible (Kimmons et al., 2020). Lastly, PSTs' lack of exposure to high-impact technology integration is a potential factor. As noted by Foulger et al., (2017), it is crucial that teacher educators "model approaches for aligning the content being taught with appropriate pedagogy and technology" (p. 432). Without appropriate and efficient modeling of high-impact technology integration, PSTs may simply be unaware of the potential to integrate technology in more meaningful ways. Regardless, further research in relation to these three potential factors may provide useful insight on K-8 PSTs' technology integration abilities.

Anticipated Student Performance

The analysis of Q2 (How do K-8 PSTs anticipate that their future students might perform in geometry activities that utilize a technological resource that they created?) suggested that PSTs are more likely to consider potential challenges when planning a technology-infused

geometry activity rather than anticipated student learning outcomes. When discussing anticipated learning outcomes, most PSTs thought students might complete the activity by sorting shapes by similarities, demonstrating knowledge of properties, or comparing 2D and 3D shapes. Overall, the anticipated student learning outcomes discussed by PSTs were well aligned with the van Hiele levels relevant to their created activities (e.g., Level 0 and Level 1). Challenges commonly noted by PSTs related to students confusing the properties of various shapes, focusing on irrelevant shape characteristics, or not understanding the difference between 2D and 3D shapes. Interestingly, few PSTs (n = 5, 12.8%) discussed challenges that were related to the use of technology. Prior research has found that K-8 PSTs were concerned that the use of technology in mathematics might have a negative impact on students' learning by reducing the activity's focus on content—especially when using games that lack significant mathematics content (Meyerink & Luo, 2022a). Most PSTs in this study (n = 27, 64.3%) utilized a mathematical game in their activity, but few considered the challenges that might arise due to the technology itself.

Proposed Methods of Assistance

The themes identified during the analysis of Q3 (What pedagogical considerations do K-8 PSTs specify when creating geometry activities that utilize a technological resource?) showed that most PSTs planned to assist students by reviewing concepts, demonstrating concepts, or providing students with additional resources. Methods of assistance that were discussed less frequently included additional questioning, leading a whole-class discussion, encouraging collaboration, and using physical models. Interestingly, using physical models to assist students was only discussed by four PSTs (9.8%). This finding suggests that PSTs were not considering the implications of the CRA sequence when thinking about how to assist students. When

learning in alignment with the CRA sequence, students consider multiple models when exploring a mathematics concept. If students were struggling with the content when only using a representational model (e.g., virtual model), a teacher with knowledge of the CRA sequence would likely integrate the use of physical/concrete models to help explain the concept. This finding, along with PSTs' questions about how to appropriately integrate technology into K-8 mathematics (Meyerink & Luo, 2022a), suggests that PSTs do not understand the role of technology in relation to other representations of mathematics concepts. More so, PSTs tended to propose methods of assistance that are teacher-centered (i.e., reviewing concepts, demonstrating concepts, providing additional resources, or leading a whole-class discussion) rather than proposing student-centered methods (e.g., posing additional questions, encouraging collaboration, or providing a physical model). This finding suggests that PSTs' notion of how students learn mathematics may be informed by a belief that students must be told about certain ideas before they are able to reason about the ideas. While this study did not gather data to further examine this topic, this is an interesting avenue for future research.

Limitations

A limitation of this study is that a convenience sample of K-8 PSTs were recruited from a single postsecondary institution, so the findings may not be generalizable to other populations of PSTs. Additionally, this cross-sectional study describes how PSTs create geometry activities that utilize a technological resource at a single point in time, which may not align with their creation abilities at other points in time. Lastly, since this study only examined how PSTs created geometry activities aligned with van Hiele's Level 0 or Level 1, the findings may not be

generalizable to other van Hiele levels or other strands of mathematics, such as number sense, measurement, statistics, etc.

When conducting research in classrooms, contamination is always a potential limitation related to the study's internal validity. PSTs were instructed to respond to the prompt independently and the researchers did not locate evidence of any collaboration between PSTs. Thus, though no evidence of contamination was discovered, it is possible that contamination impacted the findings of this study. Another potential limitation related to internal validity is the impact of the two-day lesson on PSTs' ability to create geometry activities that utilize a technological resource. While recognizing this potential impact, the researchers also recognized that withholding information about K-8 geometry to PSTs would be unethical, so teaching the lesson was deemed a necessary aspect of this study.

The last limitation of this study—and likely all social science research during this time period—is the potential impact of COVID-19 protocols. At this study's research site, the spring and fall course sections were offered in different formats due to variable COVID-19 protocols. The spring section was offered in a hybrid format due to a room capacity restriction of 15 students. In this section, an alternating, two-group hybrid design was used throughout the semester. At each course meeting, half of the class attended in-person while the other half attending either synchronously via Webex or asynchronously. The room capacity restriction was removed for the fall semester, so the whole class met in-person for the duration of the semester. While the course content remained the same for both sections and no major differences in the findings between PSTs in each semester were identified, the researchers feel this potential limitation warrants recognition.

Implications of Findings and Future Research

Based on the findings of this study, K-8 PSTs seem to be well-prepared to integrate technology into mathematics in ways that align with the IA level of the PICRAT model. These findings are encouraging since interactive uses of technology encourages lasting, meaningful learning (Kennewell et al., 2008) and technology integration aligned with the amplification level is associated with benefits to students' learning outcomes (Hughes et al., 2006). However, these findings also suggest that K-8 PSTs are not prepared to integrate technology into mathematics in ways that align with high-impact levels of the PICRAT model (e.g., CA, IT, and CT). As previously mentioned, factors that are potentially related to this finding include PSTs' lack of technology integration abilities, the technology's lack of potential to be used in a way that aligns with high-impact use, and PSTs' lack of exposure to high-impact uses of technology. While this study did not examine the impact of these factors on K-8 PSTs' creation of geometry activities that utilize a technological resource, these avenues of future research warrant investigation. Lastly, the findings of this study seemed to highlight PSTs' lack of understanding of technology integration in relation to the CRA sequence when considering how to assist students who are using technological resources to explore geometry concepts. Further research in regard to this topic—perhaps expanding to include more van Hiele levels or other strands of mathematics—may provide more insight on PSTs' understanding of technology's role in the K-8 mathematics curriculum. Additionally, teacher education programs may like to consider addressing technology integration through the lens of the CRA sequence to enhance PSTs' understanding of the role that technology assumes in the CRA sequence.

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CHAPTER FIVE

CONCLUSION

Each of these studies examined one of the three aspects outlined in the conceptual framework regarding the "planning stage" of technology integration in order to analyze PSTs' preparedness to integrate technology into mathematics. These studies uncovered information regarding PSTs' perspectives, anticipated practices, and abilities related to technology integration. In this chapter, I present a summary of the findings of each manuscript, provide a discussion that integrates these findings in relation to the overall purpose of the dissertation, and highlight potential areas of future research that may enhance our understanding of K-8 PSTs' preparedness to integrate technology into mathematics.

Summary of Findings

While the three manuscripts contributed to the overarching investigation of K-8 PSTs' preparedness to integrate technology into mathematics, each manuscript contained unique findings specific to its distinct research topic. In this section, I summarize the research findings of each of the three manuscripts in this dissertation.

Manuscript I

In addition to utilizing both the SAMR and PICRAT models to allow for a comparison of these two theoretical frameworks, the first manuscript explored the following research questions:

Q1. What knowledge of technology integration in mathematics do K-8 PSTs possess?

Q2. What questions/concerns do K-8 PSTs have regarding technology integration in mathematics?

Q3. What are K-8 PSTs' anticipated technology integration practices for their future mathematics classrooms?

Q4. For K-8 PSTs' proposed uses of technology in mathematics, how would the technological resource impact mathematics instruction?

Findings in regard to Q1 showed that while most K-8 PSTs were able to demonstrate at least some knowledge of technology integration, 36.8% of PSTs explicitly reported a lack of knowledge of technology integration in mathematics. In their responses, 38.6% of PSTs discussed specific technological resources, such as Khan Academy or GeoGebra. Others presented knowledge related to pedagogical considerations (i.e., student-centered use, establishing expectations, and differentiation; 38.6%); mathematical games (26.3%); or specific technological devices (i.e., Chromebooks and SMART Boards; 21.1%). For PSTs who reported some knowledge of technology integration, their responses suggested a familiarity with technological resources and devices but did not frequently discuss the actual integration of technology.

The analysis of Q2 found that K-8 PSTs primarily had questions/concerns related to how to appropriately use technology in the mathematics classroom (i.e., purpose and frequency; 33.3%). Some PSTs (33.3%) asked questions about how to use technology without compromising the value of the mathematics content while others (27.8%) expressed concerns about students' safety in regard to inappropriate advertisements, monitoring students' internet activity, and potential risks associated with increased screen time. Lastly, several PSTs (27.8%)

expressed concerns with students' misuse of technology (i.e., time off-task and non-mathematical games). Overall, PSTs' questions and concerns addressed technology itself but primarily focused on the integration of technology.

Findings in regard to Q3 showed that the vast majority of K-8 PSTs plan to integrate technology into their mathematics lessons relatively frequently (e.g., 17.6% *very frequently* and 41.2% *somewhat frequently*). When asked what they thought was the most practical application of technology in the mathematics classroom, PSTs frequently discussed using technology for student-centered practice (31.6%), assessment (31.6%), differentiated instruction (31.6%), or to promote the development of conceptual understanding through the use of virtual manipulatives (26.3%). While PSTs' responses were well-distributed amongst these four themes, using technology for student-centered practice was discussed most in-depth.

The analysis of Q4 found that the vast majority of K-8 PSTs' proposed uses of technology in mathematics that aligned with the IA (interactive, amplification; P4: 66.7%, P5: 78.9%) level of the PICRAT model and the augmentation level (P4: 55.6%, P5: 73.7%) of the SAMR model. Their proposed uses often included the use of interactive technological resources (i.e., virtual manipulatives and mathematical games) that amplified instruction by providing students with instant feedback. Other levels less frequently observed included the PA (passive, amplification; P4: 11.1%, P5: 5.3%) and CT (creative, transformation; P4: 11.1%, P5: 10.5%) levels of the PICRAT model and the substitution (P4: 16.7%, P5: 10.5%), modification (P4: 22.2%, P5: 10.5%), and transformation (P4: 5.6%, P5: 5.3%) levels of the SAMR model. In addition, PSTs' responses in regard to Q1, Q2, and Q3 were generally aligned with the IA level of the PICRAT model and the augmentation level of the SAMR model—often discussing

students' interactive use of technology and ways in which technology use may benefit students' learning outcomes.

Lastly, the comparison of utilizing both the SAMR and PICRAT models in this study highlighted the utility and reliability of the PICRAT model. Interrater reliability levels were similar for both the SAMR and PICRAT models and achieved the minimum recommendation for percent agreement suggested by Creswell and Poth (2017). Additionally, the PICRAT model provided a unique lens through which students' relationship with technology was highlighted while this perspective was not featured when viewing technology integration through the lens of the SAMR model.

Manuscript II

In the second manuscript, four research questions were examined:

Q1. In existing geometry activities that utilize a technological resource evaluated by K-8 PSTs, how would the resource impact mathematics instruction?

Q2. What do K-8 PSTs like about existing geometry activities that utilize a technological resource?

Q3. What do K-8 PSTs dislike about existing geometry activities that utilize a technological resource?

Q4. What characteristics of existing geometry activities that utilize a technological resource inform K-8 PSTs' interest in implementing the activity in their future classrooms?

Findings in regard to Q1 showed that 65.9% of the geometry activities evaluated by K-8 PSTs utilized a technological resource in alignment with the IA level of the PICRAT model. Often, the activities aligned with the IA level utilized an interactive mathematical game that

provided students with instant feedback. Other levels of the PICRAT model that were observed less frequently in this study included PA (13.6%), IR (interactive, replacement; 11.4%), CA (creative, amplification; 4.5%), PR (passive, replacement; 2.3%), and CT (2.3%). Interactive uses of technological resources were most common, as resources that would be used for either passive or creative learning were only observed in 15.9% and 6.8% of PSTs' responses. While most of the activities evaluated by PSTs utilized a mathematical game (68.2%), others utilized either virtual manipulatives (29.5%) or virtual demonstrations (6.8%).

The analysis of Q2 found that K-8 PSTs most frequently liked the content of the geometry activity (i.e., quality mathematics content [38.6%], variety [22.7%], and a relevant context [20.5%]). Others liked specific design aspects of the technological resource utilized in the activity, such as the resource's ease of use (18.2%) or the interactive nature of the resource (13.6%). Lastly, some PSTs liked aspects related to pedagogy, including the inclusion of instant feedback (15.9%) and the activity's potential to be used to scaffold instruction (15.9%).

Findings in regard to Q3 showed that—when identifying aspects of the geometry activity that they disliked—K-8 PSTs most frequently discussed topics related to the pedagogical implications of the activity, such as the activity having a limited application (i.e., repetitive, not challenging, age- or skill-specific, or lack of differentiation; 39.0%) or a lack of instant feedback (9.8%). Some PSTs disliked the content of the activity, noting that the content was either too limited (26.8%) or included solutions that may be misleading (7.3%). Others reported that they did not like aspects related to the design of the technological resource and suggested that the structure of the resource would restrict students' learning in some way (31.2%). Lastly, a small group of PSTs (9.8%) stated that there were no aspects of the activity that they disliked.

The analysis of Q4 showed that the vast majority of K-8 PSTs (93.2%) stated that they would use the geometry activity in their future mathematics classroom. When explaining their rationale for this decision, PSTs tended to discuss topics related to pedagogy—often describing how the activity could be useful to either introduce content (27.3%), review content (22.7%), or allow students to practice newly-learning content (20.5%). One-fourth (25.0%) of PSTs' intentions to use the activity in the future was informed by the value and quality of the mathematics content included in the activity. A small group of PSTs (13.6%) based their rationale on the design of the technological resource utilized in the activity, noting that the resource itself would likely increase students' engagement. Lastly, several PSTs (20.5%) stated that they would use the activity in the future but did not specify what informed their intent.

Manuscript III

Lastly, the third manuscript analyzed the following research questions:

Q1. In geometry activities that utilize a technological resource created by K-8 PSTs, how would the resource impact mathematics instruction?

Q2. How do K-8 PSTs anticipate that their future students might perform in geometry activities that utilize a technological resource that they created?

Q3. What pedagogical considerations do K-8 PSTs specify when creating geometry activities that utilize a technological resource?

Findings in regard to Q1 showed that K-8 PSTs (54.8%) most frequently created geometry activities that aligned with the IA level of the PICRAT model. Often, these activities utilized a mathematical game that would ask students to drag geometric shapes into categories and provide students with instant feedback. Several PSTs (16.7%) created an activity that aligned

with the IR level, which often featured the use of virtual manipulatives that did not provide instant feedback or other obvious benefits to students' learning outcomes. Less frequently, PSTs' created activities aligned with the PA (14.3%), PR (7.1%), and CR (creative, replacement; 7.1%) levels of the PICRAT model. Though PSTs' integration of mathematical games was prominent in this study (64.3%), some PSTs utilized virtual manipulatives (31.0%), a lesson located on a website (2.4%), or a mathematics video (2.4%). Lastly, PSTs' activities were well aligned with the requested levels of the van Hiele model of geometric thought, as all of the activities aligned with either Level 0 (81.0%) or Level 1 (19.0%).

The analysis of Q2 found that K-8 PSTs tended to discuss anticipated challenges (97.5%) rather than anticipated learning outcomes (70.0%) when discussing how their future students might perform on their geometry activities. Of the 39 PSTs that identified anticipated challenges, most discussed students' understanding of properties (30.8%); students focusing on properties that are not relevant to a shape's classification, such as color, size, and orientation (20.5%); or students' understanding of the difference between two-and three-dimensional shapes (20.5%). Additional challenges identified by PSTs included students being able to understand: (a) the criteria for sorting shapes (12.8%), (b) how to use technological resources (12.8%), and (c) geometry terminology (12.8%). Of the 28 PSTs that discussed anticipated learning outcomes, the majority described how students would complete the activity by correctly sorting shapes based on their visual characteristics (60.7%). Other PSTs noted that they anticipated students' learning outcomes to highlight: (a) their knowledge of specific properties (28.6%), (b) a comparison of two- and three-dimensional shapes (25.0%), or (c) their knowledge of shape composition (10.7%).

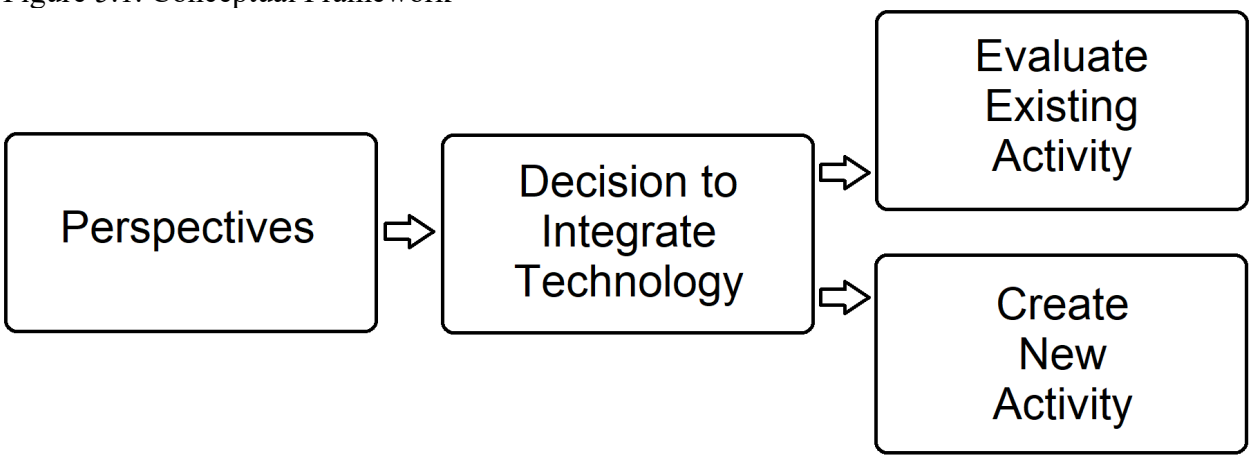
Findings in regard to Q3 showed that the largest proportion of K-8 PSTs (34.1%) planned to assist students and/or address challenges during the geometry activity they created by reviewing concepts (i.e., discussing visual characteristics, properties, or sorting). Other methods proposed by PSTs included demonstrating concepts (22.0%), providing additional resources (i.e., definitions, classifying guides, and videos; 19.5%), additional questioning (14.6%), leading a whole-class discussion (12.2%), encouraging collaboration (9.8%), or using a physical model (9.8%). Overall, PSTs' proposed methods of assisting students and/or addressing challenges tended to be teacher-centered rather than student-centered and suggested a lack of understanding of the CRA sequence due to the low proportion of PSTs that discussed physical models.

Discussion and Implications

When considering the findings of each of the three manuscripts in relation to the overall purpose of this dissertation, it is useful to revisit the conceptual framework that guided the overall design of this dissertation (Figure 5.1). The conceptual framework outlines aspects of technology integration that occur prior to implementation—conceptualized as the "planning stage" in this dissertation. As identified by previous research, K-8 PSTs' perspectives on technology integration, such as their knowledge of and attitudes toward technology integration, contribute to their technology integration practices and abilities (Crompton, 2015). More so, a distinction can be made when considering PSTs' technology integration practices and abilities. After deciding to integrate technology into a lesson, one can either make use of an existing activity that utilizes a technological resource—likely conducting an evaluation of the activity and considering potential modifications—or create a new activity that utilizes a technological resource. Thus, the findings of the three manuscripts in this dissertation can be examined in

respect to the relationships between these factors highlighted in the conceptual framework. However, caution should be practiced when connecting the findings of Manuscript I to the findings in both Manuscript II and III, as data for Manuscript I were collected prior to the COVID-19 pandemic and data for both Manuscript II and III were collected during the pandemic. This is notable as the sample in Manuscript I may have had different perspectives on technology integration when compared to the samples in Manuscripts II and III due to the relevance of technology integration during the pandemic. Thus, while a connection between the findings of all three manuscripts is discussed, the validity of these connections is unsure due to the unknown impact of the pandemic on PSTs' perspectives on technology integration.

Figure 5.1. Conceptual Framework



Similarly, findings ought to be interpreted thoughtfully with respect to the limitations identified in each manuscript—especially in regard to the generalizability of the findings. As noted, the population of each study included K-8 PSTs enrolled in K-8 Math Methods at a large postsecondary institution in the Northwest region of the United States—primarily White, female PSTs in their third or fourth year of undergraduate study. Thus, findings may not be generalizable to other groups of PSTs.

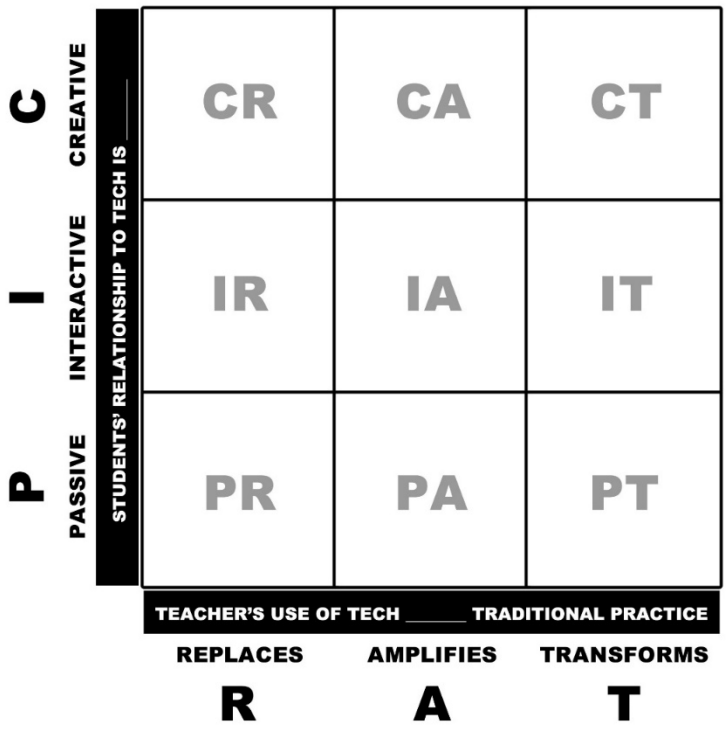
The investigation of K-8 PSTs' perspectives on technology integration yielded interesting findings. In Manuscript I, it was found that PSTs obtained somewhat limited knowledge of integrating technology into K-8 mathematics, as many explicitly reported a lack of knowledge. Additionally—though many demonstrated knowledge of familiarity with various technological resources—few PSTs discussed the actual *integration* of technological resources when reporting their knowledge of technology integration. More so, PSTs' main questions about technology integration related to how to appropriately utilize technological resources in the mathematics classroom. Similarly, topics related to pedagogy were the least commonly liked aspects and the most commonly disliked aspects of the activities evaluated by PSTs in Manuscript II.

Despite these findings, PSTs expressed positive attitudes toward technology integration. The majority of PSTs in Manuscript I most commonly planned to use technology either somewhat frequently (i.e., several times per week; 41.2%) or occasionally (i.e., an average amount; 23.5%), and 93.2% of PSTs in Manuscript II stated they would use the activity they evaluated in their future classrooms. Thus, there appears to be an interesting relationship between PSTs' perceived technology integration knowledge/skills and PSTs' attitudes toward future technology integration practices.

Overall, K-8 PSTs appear to be well-prepared to integrate technology into geometry lessons in a way that aligns with the IA level of the PICRAT model. The findings in both Manuscript II and Manuscript III showed that PSTs tended to evaluate or create an activity that utilized technological resources that would enable students' interactive learning and enhance students' learning outcomes. Additionally, PSTs seem to be most likely to integrate technology by utilizing mathematical games, as nearly two-thirds of PSTs' evaluated and created activities

involved the use of a mathematical game. In both Manuscript II and Manuscript III, the second-most common resource utilized in activities was virtual manipulatives—though these were often used in a way that replaced pedagogical practices rather than amplifying or transforming practices. Notably, very few PSTs' activities aligned with the transformation level of the RAT portion of the PICRAT model in either study. This potentially relates to PSTs' questions about technology integration in Manuscript I, as their questions most frequently related to the appropriate use of technology in the mathematics classroom.

Figure 5.2. The PICRAT Matrix

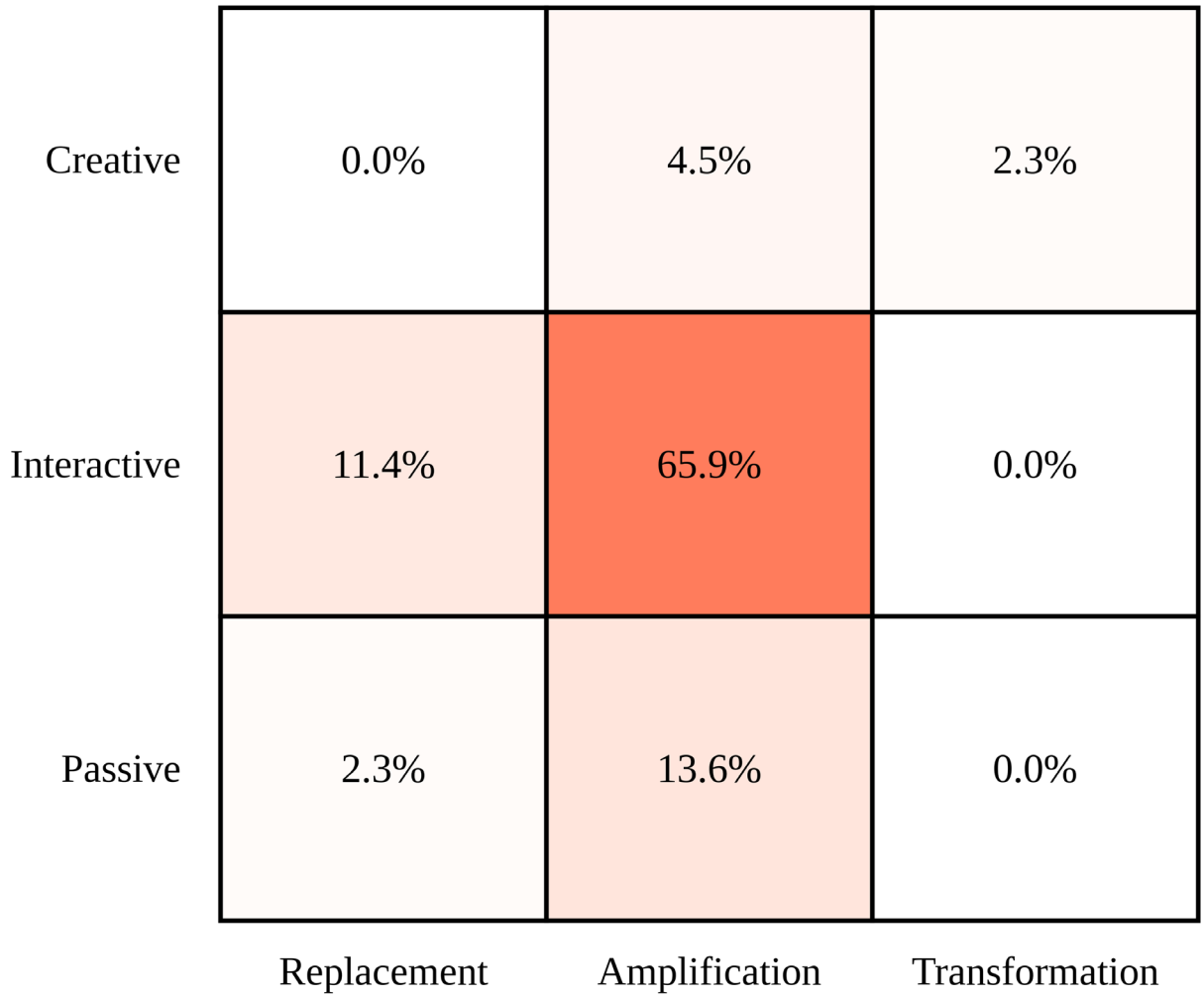


Note. From "The PICRAT Model for Technology Integration in Teacher Preparation," by R. Kimmons, C. R. Graham, and R. E. West, 2020, *Contemporary Issues in Technology and Teacher Education*, *20*(1), p. 189 (https://citejournal.org/volume-20/issue-1-20/general/the-picrat-model-for-technology-integration-in-teacher-preparation/). CC BY 3.0.

When comparing K-8 PSTs' evaluation and creation of geometry activities that utilize a technological resource, the findings in Manuscript II and Manuscript III suggest that PSTs' are more likely to integrate technology in a more impactful way when using an existing resource. Kimmons et al. (2020) organized the PICRAT model as a hierarchical matrix and noted that the use of technology's overall impact on instruction increases from the bottom-left corner to the top-right corner, as shown in Figure 5.2.

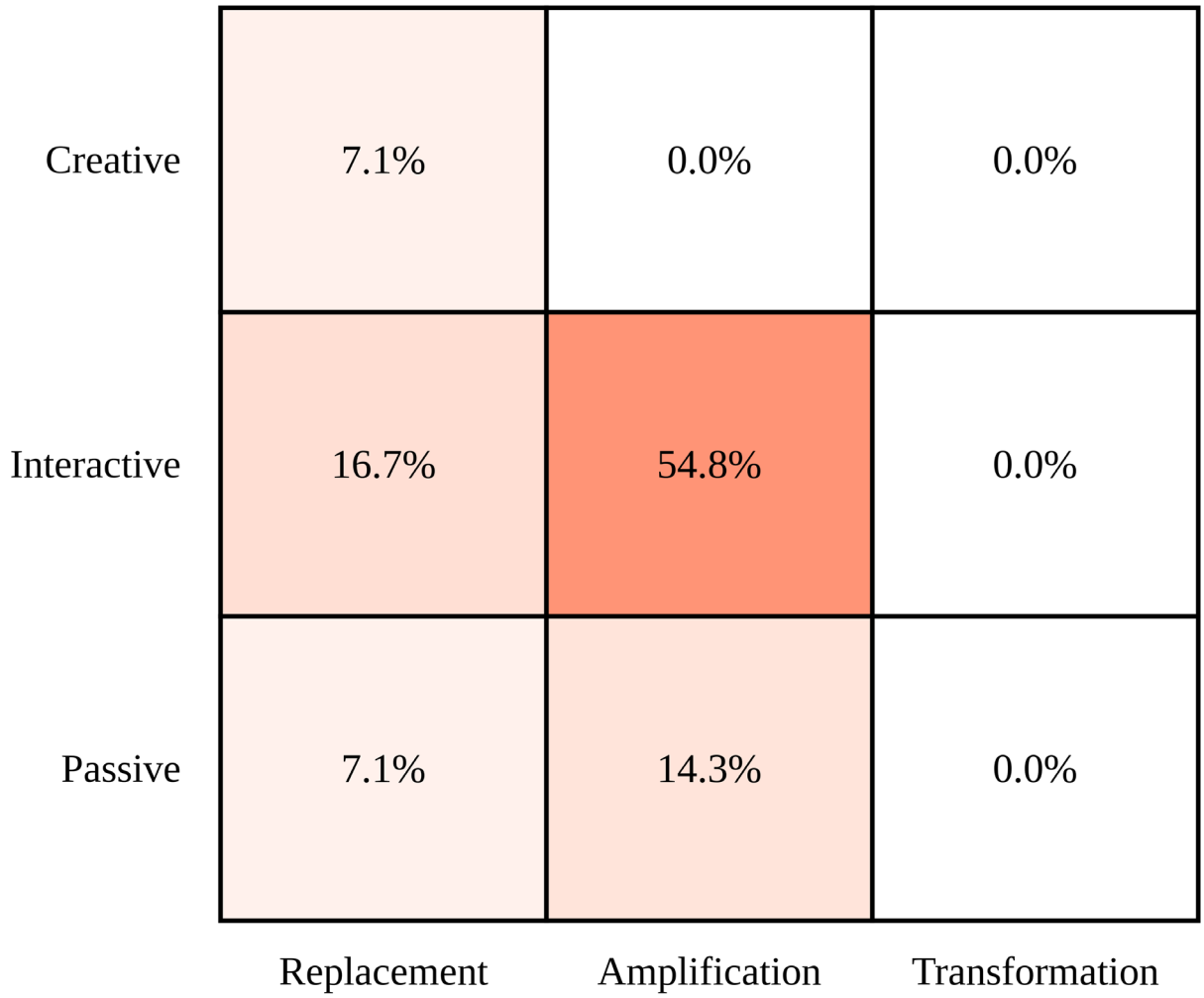
When examining PSTs' geometry activities in recognition of the hierarchical aspect of the PICRAT model, it can be seen that PSTs' activities were more likely to align with levels associated with a higher impact on instruction when existing activities were evaluated by PSTs rather than when activities were created. Notably, 65.9% of PSTs' evaluated activities in Manuscript II aligned with the IA level of the PICRAT model while just 54.8% of PSTs' created activities in Manuscript III aligned with IA. More so, the PICRAT heatmaps shown in Figure 5.3 and Figure 5.4 show that a greater proportion of "low-impact" levels (i.e., PR, IR, and PA) of the PICRAT model were observed when PSTs created activities and greater proportions of both "medium-impact" (i.e., CR, IA, and PT) and "high-impact" levels (i.e., CA, IT, and CR) were observed when PSTs evaluated existing activities. Thus, it seems that PSTs are more likely to integrate technology into geometry lessons in a way that significantly impacts instruction when utilizing existing activities rather than creating new activities. This finding is potentially related to PSTs' self-reported lack of technology integration knowledge in Manuscript I, as creating a new activity likely demands a greater understanding of technology integration when compared to evaluating an existing activity.

Figure 5.3. PSTs' Evaluation of Existing Geometry Activities



Note. "Low-impact" = 27.3%, "medium-impact" = 65.9%, and "high-impact" = 6.8%.

Figure 5.4. PSTs' Creation of Geometry Activities



Note. "Low-impact" = 38.1%, "medium-impact" = 61.9%, and "high-impact" = 0.0%.

Lastly, the findings outlined in this dissertation provide useful insight for teacher education programs. It appears that K-8 PSTs' need more guidance related to integrating technology into mathematics—especially in regard to pedagogical considerations associated with the actual *integration* of technology. More so, the findings suggest that "high-impact" uses of technology in the mathematics classroom (i.e., the CA, IT, and CT levels of the PICRAT model) are potentially not being modeled in teacher education programs (Foulger et al., 2017). If true,

PSTs may be relying on the technology integration practices they observed as students to conceptualize technology integration (Lortie, 1975). Thus, teacher education programs ought to search for instructional methods that may increase PSTs' abilities to take advantages of the affordances of technological resources—perhaps by including an explicit use of the PICRAT model in PSTs' methods courses as recommended by Kimmons and colleagues (2020) or by providing PSTs with opportunities to use technology in K-8 classrooms prior to degree completion as recommended by Graham and colleagues (2008). Regardless of the approach, teacher education programs need to explore instructional methods that might increase PSTs' abilities to utilize technology in ways that provide benefits to both students' learning outcomes and their own pedagogical practices.

Areas of Future Research

When considering areas of future research of K-8 PSTs' preparedness to integrate technology into mathematics that build on the findings of this dissertation, several topics stand out: (a) examining other strands of mathematics and grade levels, (b) observing the transition of anticipated practices to demonstrated practices, (c) exploring the difference between PSTs' abilities to evaluate or create activities, and (d) examining PSTs' perspectives through the lens of one's technology identity.

One potential avenue of future research relates to this dissertation's focus on early-grade geometry activities that utilize a technological resource. The decision to focus on a single strand of mathematics was based on the likely possibility that K-8 PSTs' abilities to integrate technology into mathematics vary by strand (e.g., number sense, measurement, statistics, algebra, etc.). For example, one might be especially skilled in integrating technology into geometry

lessons due to a strong understanding of geometry concepts, but less adept at integrating technology into statistics lessons due to a lack of understanding of statistics concepts. Similarly, the decision to focus on van Hiele's (1959/1984) Level 0 and Level 1 was based on the potential that PSTs' abilities to integrate technology vary by the grade level of the intended students. Thus, future research could employ a similar research design but instead examine PSTs' technology integration abilities in relation to other strands of mathematics and/or other van Hiele levels. This research would provide a more complete understanding of PSTs' abilities as well as allow for examinations across strands and grades.

Another topic of future research relates to this dissertation's focus on *anticipated* practices rather than *demonstrated* practices. While gaining information on K-8 PSTs' preparedness to integrate technology is helpful in understanding their future practices, a beneficial approach might be to continue research on this population as they transition from PSTs to in-service teachers (ISTs). This design may provide insight on several areas of interest, such as: (a) whether PSTs' technology integration perspectives and abilities impact their technology integration practices as ISTs, (b) whether ISTs' technology integration perspectives and abilities change after gaining experience in the classroom, and (c) what factors cause ISTs' technology integration perspectives and abilities to either increase or decrease. While this is likely a more challenging research design, examining the transition from PST to IST may prove to be invaluable in understanding teachers' integration of technology into mathematics.

While differences between K-8 PSTs' evaluation and creation of geometry activities that utilize a technological resource were observed in this dissertation, a sure explanation of these differences was not evident. As mentioned, this finding could potentially be related to PSTs' lack

of knowledge or their pedagogical questions/concerns related to technology integration. Future research that seeks to identify factors that contribute to these observed difference would likely advance our understanding of the factors that influence PSTs' abilities to both evaluate and create activities that utilize technological resources. More so, this observed difference could be a product of the potentially varying availability of technology-infused activities that are aligned with various levels of the PICRAT model (e.g., existing activities that use technology in a way that align with either the CA, IT, or CT levels of the PICRAT model may be rare, challenging to locate, or require payment), which is another topic that ought to be explored.

As previously noted, K-8 PSTs' reported technology integration knowledge and questions/concerns about technology integration in Manuscript I are potentially indicative of their abilities to evaluate and create geometry activities that utilize a technological resource. Additionally, Manuscript I highlighted an interesting relationship between PSTs' knowledge, questions, and concerns and their attitudes toward technology integration in mathematics. Due to these findings, future research that focuses on capturing a more holistic understanding of PSTs' perspectives is warranted. A framework that might be useful in this regard is Goode's (2010) conceptualization of one's technology identity. This theory describes technology identity as: "beliefs about one's own technology abilities; beliefs about the importance of technology; beliefs about participation opportunities and constraints that exist; and one's sense of motivation to learn more about technology" (Goode, 2010, p. 502). Potential research topics related to technology identity that may be beneficial to understanding PSTs' preparedness for technology integration might include: (a) describing PSTs' perspectives on technology integration through the lens of technology identity, (b) utilizing PSTs' technology identities as a predictor of technology

integration practices through the lens of the PICRAT model, and (c) examining the impact of various teacher education program practices (e.g., explicit PICRAT model instruction [Kimmons et al., 2020] or field experiences focused on technology integration [Graham et al., 2008]) on PSTs' technology identities. While very few studies have applied Goode's theoretical perspective to PSTs and more work needs to be done to standardize and validate the measurement of one's technology identity, this conceptual approach may prove to be especially beneficial in understanding PSTs' preparedness to integrate technology into mathematics in relation to their perspectives, anticipated practices, and abilities.

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APPENDICES

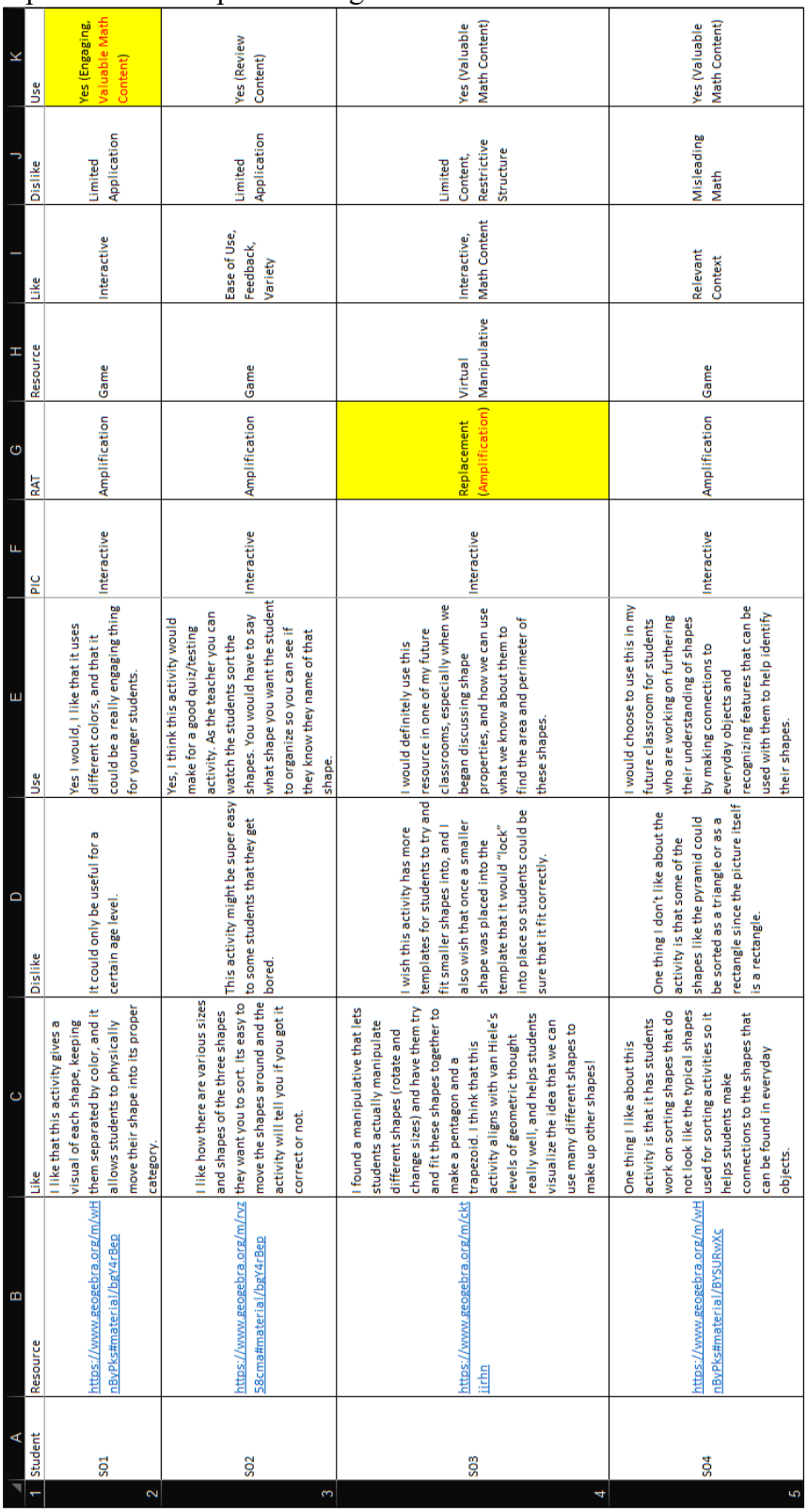
APPENDIX A

EXAMPLES OF *A PRIORI* AND EMERGENT CODING

Figure 6.1. Example of Manuscript I Coding

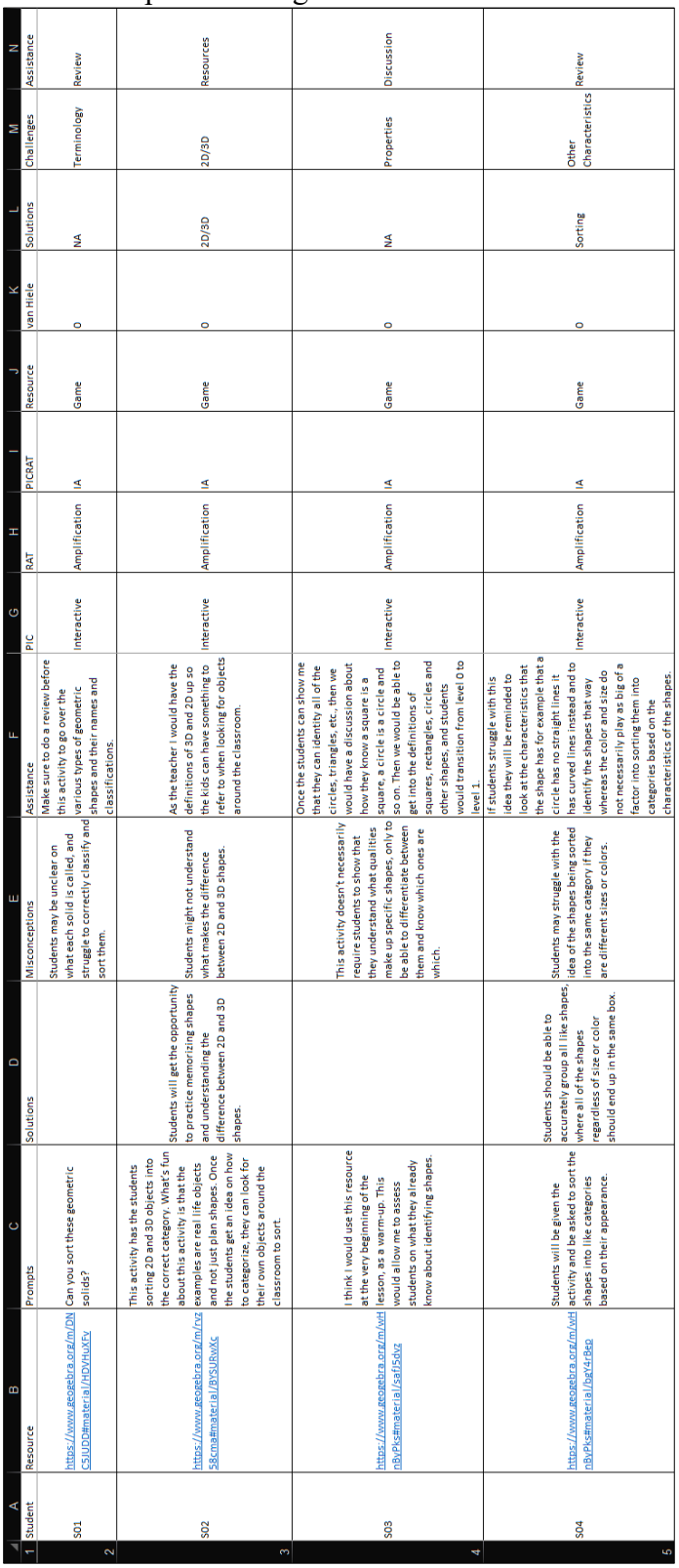
	A	B	C	D	E	F	G	H	I	J
1	Student	(P1) What do you know about using educational technology in the mathematics classroom?	PIC (M)	RAT (M)	SAMR (M)	Themes (M)	PIC (F)	RAT (F)	SAMR (F)	Themes (F)
2	S01	This past fall I was in Practicum 1, and in my class students had their own Chromebooks where they did math and writing practice. This has increased my knowledge about technology in the math classroom. They were used in a specific way; only after students first learned the steps of the math via the teacher and handwritten practice on paper. Then one of the stations during math time was on the computer where they did math that was at their level. I had some experience with a student using a calculator when they were not allowed, so in the technology aspect of the calculator I have also had some experience.	Interactive	Amplification	Augmentation	Devices, Pedagogy	Interactive	Amplification	Augmentation	Devices, Pedagogy
3	S02	Not much. Should be engaging and interactive. Learning games that involve math concepts/strategies.	Interactive	Amplification	Augmentation	Games, Lack of Knowledge	Interactive	Amplification	Augmentation	Games, Lack of Knowledge, Pedagogy
4	S03	Khan Academy for math videos. Kids have a way of connecting to technology that might spike their interest in a math topic if introduced through technology.	Passive	Replacement	Substitution	Resources	Passive	Amplification	Augmentation	Resources
5	S04	I don't know a whole lot, but I know that it can help with differentiation for students who learn in different ways. It can be an awesome way for students to complete projects.	Creative	Amplification	Augmentation	Lack of Knowledge, Pedagogy	Creative	Amplification	Augmentation	Lack of Knowledge, Pedagogy
6	S05	Technology is used in math classrooms constantly. From smartboards, calculators, and document cameras to software and websites - it's a valuable tool.	NA	Replacement	Substitution	Devices	NA	Replacement	Substitution	Devices
7	S06	I know that most state testing, like the star, are done online. List: Khan Academy, Pearson, scale tools, graphing calculator. Most of the teaching I've seen in classrooms are textbook, rocket math, and class activities.	NA	Replacement	Substitution	Resources	NA	Replacement	Substitution	Resources
8	S07	Things I know about integrating technology in the classroom are math-based computer games to give students practice with certain mathematical concepts.	Interactive	Amplification	Augmentation	Games	Interactive	Amplification	Augmentation	Games, Pedagogy
9	S08	My CT last year used Khan Academy for when students finished work early. I know there are other apps and games you can use but I really have not explored any.	Interactive	Amplification	Augmentation	Games, Resources	Passive	Replacement	Substitution	Games, Lack of Knowledge, Resources
10	S09	GeoGebra, Tinkerkad, graphing calculators, math modeling - use technology for research, learning glass - record math lessons.	Creative	Transformation	Modification	Devices, Resources	Creative	Transformation	Redefinition	Devices, Resources
11	S10	There's a website for kids to go onto where they complete math problems. Each math problem they finish, they receive so many seconds. After collecting 2 minutes or more, they are able to play games for the amount of time won. Educational technology allows students a different way of learning math other than using paper and the teacher lecturing.	Interactive	Amplification	Augmentation	Games, Pedagogy	Interactive	Amplification	Augmentation	Games, Pedagogy

Figure 6.2. Example of Manuscript II Coding



	A	B	C	D	E	F	G	H	I	J	K
1	Student	Resource	Like	Dislike	Use	PIC	RAT	Resource	Like	Dislike	Use
2	S01	https://www.geogebra.org/m/wHnByPks#material/bgY4rBep	I like that this activity gives a visual of each shape, keeping them separated by color, and it allows students to physically move their shape into its proper category.	it could only be useful for a certain age level.	Yes I would, I like that it uses different colors, and that it could be a really engaging thing for younger students.	Interactive	Amplification	Game	Interactive	Limited Application	Yes (Engaging, Valuable Math Content)
3	S02	https://www.geogebra.org/m/ryzs8cma#material/bgY4rBep	I like how there are various sizes and shapes of the three shapes they want you to sort. Its easy to move the shapes around and the activity will tell you if you got it correct or not.	This activity might be super easy to some students that they get bored.	Yes, I think this activity would make for a good quiz/testing activity. As the teacher you can watch the students sort the shapes. You would have to say what shape you want the student to organize so you can see if they know they name of that shape.	Interactive	Amplification	Game	Ease of Use, Feedback, Variety	Limited Application	Yes (Review Content)
4	S03	https://www.geogebra.org/m/cktiirhn	I found a manipulative that lets students actually manipulate different shapes (rotate and change sizes) and have them try and fit these shapes together to make a pentagon and a trapezoid. I think that this activity aligns with van Hiele's levels of geometric thought really well, and helps students visualize the idea that we can use many different shapes to make up other shapes!	I wish this activity has more templates for students to try and fit smaller shapes into, and I also wish that once a smaller shape was placed into the template that it would "lock" into place so students could be sure that it fit correctly.	I would definitely use this resource in one of my future classrooms, especially when we began discussing shape properties, and how we can use what we know about them to find the area and perimeter of these shapes.	Interactive	Replacement (Amplification)	Virtual Manipulative	Interactive, Math Content	Limited Content, Restrictive Structure	Yes (Valuable Math Content)
5	S04	https://www.geogebra.org/m/wHnByPks#material/8YSURwXc	One thing I like about this activity is that it has students work on sorting shapes that do not look like the typical shapes used for sorting activities so it helps students make connections to the shapes that can be found in everyday objects.	One thing I don't like about the activity is that some of the shapes like the pyramid could be sorted as a triangle or as a rectangle since the picture itself is a rectangle.	I would choose to use this in my future classroom for students who are working on furthering their understanding of shapes by making connections to everyday objects and recognizing features that can be used with them to help identify their shapes.	Interactive	Amplification	Game	Relevant Context	Misleading Math	Yes (Valuable Math Content)

Figure 6.3. Example of Manuscript III Coding



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Student	Resource	Prompts	Solutions	Misconceptions	Assistance	PIC	RAT	PICRAT	Resource	van Hiele	Solutions	Challenges	Assistance
2	S01	https://www.geogebra.org/m/DNC5JUDD#material/HDVHuXFv	Can you sort these geometric solids?		Students may be unclear on what each solid is called, and struggle to correctly classify and sort them.	Make sure to do a review before this activity to go over the various types of geometric shapes and their names and classifications.	Interactive	Amplification	IA	Game	0	NA	Terminology	Review
3	S02	https://www.geogebra.org/m/cvz58cma#material/B9SUBvKc	This activity has the students sorting 2D and 3D objects into the correct category. What's fun about this activity is that the examples are real life objects and not just plain shapes. Once the students get an idea on how to categorize, they can look for their own objects around the classroom to sort.	Students will get the opportunity to practice memorizing shapes and understanding the difference between 2D and 3D shapes.	Students might not understand what makes the difference between 2D and 3D shapes.	As the teacher I would have the definitions of 3D and 2D up so the kids can have something to refer to when looking for objects around the classroom.	Interactive	Amplification	IA	Game	0	2D/3D	2D/3D	Resources
4	S03	https://www.geogebra.org/m/wtnpPkse#material/sat05dvz	I think I would use this resource at the very beginning of the lesson, as a warm-up. This would allow me to assess students on what they already know about identifying shapes.		This activity doesn't necessarily require students to show that they understand what qualities make up specific shapes, only to be able to differentiate between them and know which ones are which.	Once the students can show me that they can identify all of the circles, triangles, etc., then we would have a discussion about how they know a square is a square, a circle is a circle and so on. Then we would be able to get into the definitions of squares, rectangles, circles and other shapes, and students would transition from level 0 to level 1.	Interactive	Amplification	IA	Game	0	NA	Properties	Discussion
5	S04	https://www.geogebra.org/m/wtnpPkse#material/bat4rBep	Students will be given the activity and be asked to sort the shapes into like categories based on their appearance.	Students should be able to accurately group all like shapes, where all of the shapes regardless of size or color should end up in the same box.	Students may struggle with the idea of the shapes being sorted into the same category if they are different sizes or colors.	If students struggle with this idea they will be reminded to look at the characteristics that the shape has for example that a circle has no straight lines it has curved lines instead and to identify the shapes that way whereas the color and size do not necessarily play as big of a factor into sorting them into categories based on the characteristics of the shapes.	Interactive	Amplification	IA	Game	0	Sorting	Other Characteristics	Review

APPENDIX B

PERMISSION TO REPRINT COPYRIGHTED MATERIAL

Letitia (Osmo) <support@playosmo.com> Thu, Jan 13, 2022 at 12:02 PM
Reply-To: Osmo <support@playosmo.com>
To: Montemeyerink <montemeyerink@montana.edu>

Letitia (Osmo)

Jan 13, 2022, 11:02 PST

Hello Monte,

Thanks for reaching out to Osmo with your question about reprinting the Osmo image.

Yes, you have permission to reprint the attached image in your journal article. We ask that you reference the Osmo website www.playosmo.com as the source of the image, as a way to respect the copyright.

Please let us know if you have any other questions. Have a great day!

Best,
Letitia
Customer Experience

Osmo
[Game Manuals] [Help Center]

Montemeyerink

Jan 12, 2022, 12:04 PST

Hello,

I am a mathematics education Ph.D. candidate at Montana State University and am currently writing a journal article about preservice teachers' use of educational technology in K–8 mathematics. One of the study participants discussed the use of Osmo's tangram game, and I would like to include a picture of the Osmo in my article to increase my readers' understanding. I have attached the image that I would like to use in my article which I located at https://www.playosmo.com/en/shopping/games/tangram/. Do I have your permission to reprint this image in my journal article? If so, how do you prefer that I cite this image in my article in order to adequately respect the copyright?

Monte Meyerink

Attachment(s)

Osmo.jpeg

This email is a service from Osmo. Delivered by Zendesk

APPENDIX C

INSTITUTIONAL REVIEW BOARD APPROVALS

MONTANA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
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MEMORANDUM

TO: Monte Meyerink, Fenqjen Luo, Ciara Burgal

FROM: Mark Quinn Mark Quinn ctj
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: September 15, 2020

RE: *"Preservice Teachers' Perspectives on Technology Integration in Kindergarten through Eighth Grade Mathematics" [MM091520-EX]*

The above research, described in your submission of September 14, 2020, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

____ (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

_X_ (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation; and (iii) the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by section 16.111(a)(7).

____ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

____ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

____ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

____ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

Consent Form

I give permission to Dr. Luo and her assistants to use any of my work completed in the "School Mathematics in a Changing World" and "Planning for Teaching Diverse Students" modules for teaching and/or research purposes to benefit the mathematics education community.

Identifying information (e.g., student names) will be kept confidential in all public presentations, publications, and disseminations, and will only be disclosed with your permission or as required by law. No risks, discomforts, and/or inconveniences are expected to occur. Participation is voluntary, and the decision of whether or not to provide permission will not impact your relationship with Dr. Luo, her assistants, or the Department of Education at Montana State University. If you have questions regarding your rights, please contact Montana State University's IRB Office at 406-994-6783 or Dr. Luo at fluo@montana.edu.

Your signature (physical or electronic) indicates that you have read and understand the information provided above, that you willingly agree to give your permission that your work be used for teaching and/or research purposes, that you may withdraw your consent at any time and discontinue participation without penalty, and that you are not waiving any legal claims.

Signature: _____ Date: _____



MONTANA STATE UNIVERSITY
Request for Designation of Research as Exempt from the
Requirement of Institutional Review Board Review
(12/1/2017)

****

THIS AREA IS FOR INSTITUTIONAL REVIEW BOARD USE ONLY. DO NOT WRITE IN THIS AREA.
Confirmation Date: 12/13/21 Mark T. Quinn
Application Number:

****

DATE: 12/3/2021

-Okay as exempt
-Educational assessment
-Little/no risk
-No concerns
MQ 12/13/21

I. INVESTIGATOR(s):

Name: Monte Meyerink
Address: Department of Education, P.O. Box 172880, Bozeman, MT 59717
Telephone: 605-639-1199
E-Mail Address: montemeyerink@montana.edu
DATE TRAINING COMPLETED: 08/27/2019
Name of Faculty Sponsor: Dr. Fenqjen Luo
SIGNATURE (INVESTIGATOR): Monte Meyerink

Name: Dr. Fenqjen Luo
Address: Department of Education, P.O. Box 172880, Bozeman, MT 59717
Telephone: 406-994-5950
E-Mail Address: fluo@montana.edu
DATE TRAINING COMPLETED: 10/05/2018
SIGNATURE (INVESTIGATOR and ADVISOR): Luo, Fenqjen

II. TITLE OF RESEARCH PROJECT: (Try to keep title on first page.)

Preservice Teachers' Evaluation and Creation of K-8 Mathematics Activities that Utilize a Virtual Resource

III. BRIEF DESCRIPTION OF RESEARCH METHODS (also see section VII). If using a survey/questionnaire, provide a copy with this application.

The purpose of this study is to examine preservice teachers' evaluation and creation of K-8 mathematics activities that utilize a virtual resource. Participants will be recruited from EDM 304 K-8 Math Methods. Data consists of prompts that participants will complete during course meetings. The prompts associated with this research project are required assignments for EDM 304. There will be no negative repercussions for those who choose not to participate in the study.

IV. RISKS AND INCONVENIENCES TO SUBJECTS (also see section VII; do not answer 'None'):

The risks associated with this study are both minimal and unforeseeable. While participants' identifying information will be known by the researchers, this information will remain confidential and will never be revealed in any publication of this study.

V. SUBJECTS:

A. Expected numbers of subjects: **50**

B. Will research involve minors (age < 18 years)? Yes **No**
(If 'Yes,' please specify and justify.)

C. Will research involve prisoners? Yes **No**

D. Will research involve any specific ethnic, racial, religious, etc. groups of people?
(If 'Yes,' please specify and justify.) Yes **No**

E. Will a consent form be used? (Please use accepted format from our website. Be sure to indicate that participation is voluntary. Provide a stand-alone copy. Do not include the form here.)
Yes No

VI. FOR RESEARCH INVOLVING SURVEYS OR QUESTIONNAIRES:
(Be sure to indicate on each instrument, survey, or questionnaire that participation is voluntary.)

A. Is information being collected about:

Sexual behavior?	Yes	**No**
Criminal behavior?	Yes	**No**
Alcohol or substance abuse?	Yes	**No**
Matters affecting employment?	Yes	**No**
Matters relating to civil litigation?	Yes	**No**

B. Will the information obtained be completely anonymous, with no identifying information linked to the responding subjects? Yes **No**

C. If identifying information will be linked to the responding subjects, how will the subjects be identified?

By name	**Yes**	No
By code	Yes	**No**
By other identifying information	Yes	**No**

D. Does this survey utilize a standardized and/or validated survey tool/questionnaire? Yes **No**

VII. FOR RESEARCH BEING CONDUCTED IN A CLASSROOM SETTING:

A. Will research involve blood draws? (If 'Yes,' please follow protocol listed in the "Guidelines for Describing Risks: blood, etc.", section I-VI.) Yes **No**

VIII. FOR RESEARCH INVOLVING PATIENT INFORMATION, MATERIALS, BLOOD, OR TISSUE SPECIMENS RECEIVED FROM OTHER INSTITUTIONS:

A. Are these materials linked in any way to the patient (code, identifier, or other link to patient identity)? Yes No

B. Are you involved in the design of the study for which the materials are being collected? Yes No

C. Will your name appear on publications resulting from this research? Yes No

D. Where are the subjects from whom this material is being collected?

E. Has an IRB at the institution releasing this material reviewed the proposed project? (If 'Yes,' please provide documentation.) Yes No

F. Regarding the above materials or data, will you be:
Collecting them? Yes No
Receiving them? Yes No
Sending them? Yes No

G. Do the materials already exist? Yes No

H. Are the materials being collected for the purpose of this study? Yes No

I. Do the materials come from subjects who are:
Minors? Yes No
Prisoners? Yes No
Pregnant women? Yes No

J. Does this material originate from a patient population that, for religious or other reasons, would prohibit its use in biomedical research?
Yes No Unknown Source

IX. FOR RESEARCH INVOLVING MEDICAL AND/OR INSURANCE RECORDS

A. Does this research involve the use of:
Medical, psychiatric, and/or psychological records? Yes No
Health insurance records? Yes No
Any other records containing information regarding personal health and illness? Yes No

If you answered "Yes" to any of the items in this section, you must complete the HIPAA Worksheet.

Prompts for Participants

For each of the following prompts, the term "*mathematics*" will be replaced with terminology related to a specific topic relevant to K-8 mathematics education (e.g., computation strategies, fraction concepts/computation, decimal/percent concepts/computation, ratio/proportion concepts, measurement concepts, geometric thinking/concepts, data collection, data analysis, etc.).

Evaluation of K-8 Mathematics Activities That Utilize a Virtual Resource

Locate an existing *mathematics* activity that uses a virtual resource (include URL) and respond to the following prompts: What do you like about the activity? What do you dislike about the activity? Why would you choose to either use or not use this activity in your future classroom?

Creation of K-8 Mathematics Activities That Utilize a Virtual Resource

Design and describe a short activity using a virtual resource (include URL) that may improve students' understanding of *mathematics*. Include: (a) prompts for students, (b) anticipated student solutions, (c) potential student difficulties/misconceptions, and (d) methods of assisting students and/or addressing misconceptions.

Subject Consent Form for Participation in Human Research at Montana State University

We are asking you to participate in a research study regarding preservice teachers' evaluation and creation of K-8 mathematics activities that utilize virtual resources. We are asking you to participate in this study because you are a preservice teacher currently enrolled in EDM 304: K-8 Math Methods. Participation in this study is voluntary. Please read this form carefully and ask any questions you may have prior to agreeing to participate.

Purpose
The purpose of this study is to examine and analyze preservice teachers' evaluation and creation of K-8 mathematics activities that utilize virtual resources.

Procedures
Participation in this study is voluntary. If you agree to participate, we will examine your EDM 304 coursework, including discussion posts, assignments, and lesson plans. You may choose to withdraw from the study at any time. Withdrawal or non-participation will not impact your EDM 304 grade, relationship with the researchers, or standing in the Department of Education.

Risks and Discomforts
We do not anticipate any risks from participating in this research.

Benefits
Participants may indirectly benefit from the study by reflecting on one's knowledge of integrating technology into K-8 mathematics. In this study, we hope to learn more about preservice teachers' evaluation and creation of K-8 mathematics activities that utilize virtual resources in order to inform teacher education program curricula.

Compensation
Participants will not receive compensation for participating in this study.

Privacy/Confidentiality/Data Security
All data gathered in this study will remain confidential. No identifying information will be revealed in any presentation or publication of this study. Identifying information will only be known by the researchers. All data will be stored securely on a private computer.

Contact Information
The primary researcher conducting this study is Monte Meyerink, a graduate student at Montana State University. If you have any questions, you may contact Monte Meyerink at montemeyerink@montana.edu. If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) for Human Participants at 406-994-4706 or access their website at http://www.montana.edu/orc/irb/index.html.

Statement of Consent
I have read the above information and have received answers to any questions I asked. I consent to take part in the study by physically or electronically signing below.

Signature: _____

Date: _____

APPROVED MSU 12/14/2021
IRB #MM121421-EX