Research Highlights in Technology and Teacher Education

Todd Cherner & Rebecca Blankenship
Editors 2024 Edition

AACE
Association for the Advancement of Computing in Education

SITE
SOCIETY FOR INFORMATION TECHNOLOGY AND TEACHER EDUCATION

Research Highlights in Technology and Teacher Education

Edited by

Todd Cherner
Rebecca Blankenship

Published by

AACE-Association for the Advancement of Computing in Education

Thank you to our families for their support as we engaged this work. Our gratitude to the authors who graciously attended to recommendations and revisions through the publication process. Also, thank you to the chairs of SITE's Special Interest Groups for identifying high-quality conference submissions.

Thank you to our colleagues at SITE including Jake Cohen, Kathryn Mosby, and Sarah Benson for supporting this work, as well as all of SITE's leadership.

We would also like to recognize the many individuals who served as research participants for the studies included in this volume. Being part of a research study as a participant is an investment of time, energy, and intellect, and we are grateful they invested.

Finally, we would like to recognize the educators, technologists, students, and larger educational community. Our collective effort helps drives the purposeful use of extended reality technologies for teaching and learning. Thank you for your dedication.

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Please cite as:
Cherner, T. & Blankenship, R. (2024). *Research Highlights in Technology and Teacher Education 2024, Volume 1*. Association for the Advancement of Computing in Education (AACE). Retrieved August 26, 2024 from https://www.learntechlib.org/primary/p/224713/

ISBN: 978-1-939797-78-0

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The front cover was created by Elizabeth (Elle) Gallagher. Thank you for your contribution.

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FOREWORD

It is my pleasure to present to the technology and teacher education community the fifteenth edition of *Research Highlights in Technology and Teacher Education*. This volume contains some of the most important research happening in our field as presented at the 35th annual SITE Conference. To no one's surprise, issues related to artificial intelligence permeated much of the work presented at the conference. As we have with major technological innovations in the past, the researchers and practitioners in the SITE community are embracing the possibilities and interrogating the challenges this new technology presents at all levels and from multiple perspectives, and the quality of that scholarship is on display in this volume.

This edition of *Research Highlights in Technology and Teacher Education* is particularly special, as we welcome two new editors, Todd Cherner and Rebecca Blankenship. Drs. Cherner and Blankenship follow in the footsteps of David Gibson and Marilyn N. Ochoa, who for years ably stewarded this publication, ensuring that the important work of the SITE community is communicated as widely as possible. The SITE community is tremendously grateful for their service, and are equally excited by the energy with which Drs. Cherner and Blankenship are approaching their editorship.

SITE is the premiere place for scholars of technology and teacher education to connect, share ideas, and work together to address the most pressing issues in our field. As readers engage with the scholarship in this volume, I encourage them to consider building off the questions posed within it by submitting their own proposals to future SITE conferences, so that they might be featured in a future edition of *Research Highlights in Technology and Teacher Education*.

Jonathan D. Cohen

President, Society for Information Technology and Teacher Education

INTRODUCTION

It is an honor to serve as an editor for *Research Highlights in Technology and Teacher Education* (RHTTE), an annual publication that disseminates high-quality research presented at *the Society of Information and Technology in Teacher Education's* conference. I am extremely proud of this year's volume because of the wide swath of research topics and authors represented in it. I also want to acknowledge the chairs of all the different special-interest groups who provided recommendations of works to be included in this edition. Having their recommendations guided the selection process of articles, and I am grateful to them. Next, I'd like to provide a preview of the articles included in this edition.

- **Article 1.** Kwon, Kim, Seo, Kim, and Brush examine how embodied learning experiences in a mixed-reality setting enhance first-grade students' understanding of computational thinking concepts, revealing both beneficial congruent movements and instances of incongruence that inform the dynamics of embodied learning.
- **Article 2.** Curby, Weinburgh, and Brown explore how educators can use geospatial tools like ArcGIS to enhance students' understanding of the global impact and material composition of smartphones, fostering critical thinking and environmental awareness through location-based learning projects.
- **Article 3.** Saubern and Urbach (2024) explain how item response theory, particularly Rasch analysis, can be applied to TPACK research to provide meaningful qualitative descriptions of teachers' quantitative TPACK proficiency scores, offering a novel approach to interpreting survey results in this field.
- **Article 4.** Trevisan (2024) investigates the effectiveness of internships in initial teacher education programs, revealing an expectation gap and vulnerability to contextual pressures among pre-service teachers, particularly regarding technology integration, and recommends closer collaboration between ITE programs and internship settings to better support teachers' professional identity development.
- **Article 5.** Baumann, Tiede, Latoschik, and Grafe explore pre-service teachers' experiences with a social mixed reality environment for transcultural education, identifying opportunities and challenges to inform future practices in developing media pedagogical competence within initial teacher education programs.
- **Article 6.** Clausen, Rutledge, Borthwick, Driscoll, Jin, Sprague, Warr, and Williams use Q methodology and factor analysis to examine how teacher education candidates from seven U.S. institutions perceive their preparation to use technology, evaluating their experiences against Foulger's four pillars of technology infusion in teacher preparation programs.
- **Article 7.** Kidd, Pazos, Gutierrez, Rhemer, Ringleb, Kaipa, Kumi, Ayala, and Cima compare two instructional models for developing preservice teachers' competence in engineering education, finding that both cross-disciplinary collaboration with engineering students and education student-only teams using prepared lessons led to increased engineering knowledge and pedagogical skills, with each approach offering unique benefits.
- **Article 8.** Mishnick, McLemore, and Wise conducted a qualitative case study that reveals how an educational technology course significantly enhanced alternative teaching certification students' understanding and potential application of ISTE Standards, addressing the critical need for technology skills in teacher preparation programs.
- **Article 9.** Ozen, Cayton, McCulloch, Fye, Muthitu, Fletcher, and Bailey examine how a framework introduced in a methods course helped secondary preservice teachers develop their ability to anticipate student thinking on technology-enhanced mathematics tasks, showing a shift from self-focused thinking to student-focused anticipation.
- **Article 10.** Williams and Kell detail how rural teachers and university facilitators co-created state competencies to inform the development of accessible, adaptive online professional

learning opportunities, using human-centered approaches to address teacher retention issues in rural communities.

- **Article 11.** Von Gillern, Obubo, Lannin, and Hutchison analyze two teachers' perspectives on how engaging students in analyzing, creating, and sharing digital messages about cyberbullying enhanced students' digital citizenship skills, fostered creativity, and provided a versatile approach to addressing civic issues.

As you read across the articles, I challenge you to think about what is *next*. The next steps that can be taken to advance the line of inquiry. The next technologies that can scale the results reported in these findings, so all students prosper. The next research questions that continue to build upon these scholarly insights.

Finally, I want to express my gratitude to SITE President Jake Cohen for offering this editorship to myself, and Dr. Rebecca Blankenship for being a wonderful co-editor who took the lead on the second volume of this year's RHTTE edition. Lastly, I want to recognize the work of RHTTE's prior editors, Drs. Maddux, Gibson, Ochoa, Liu, Dodge, Koehler, Mishra, and Owens. I hope that Rebecca and I continue the tradition of this editorship.

~ Todd Cherner, Ph.D.
August, 22, 2024

THERE'S A FUTURE TO GENAI: LET'S FIND IT!

Todd Cherner
The University of North Carolina at Chapel Hill, USA
tcherner@unc.edu

Rebecca Blankenship
Florida Agricultural and Mechanical University

Generative artificial intelligence (genAI) is proving to be one of the most consequential technologies ever. A novel technology that can create text and multimedia images in response to human prompts within seconds, genAI is predicted to change education in the coming years, from instructional and assessment used by educators to ways students will complete assignments and practice skills (Acar, 2024; Heaven 2023), and we observed its collective impact at our 2024 conference in Las Vegas, Nevada. From that conference's proceedings (www.learntechlib.org/primary/j/SITE/v/2024/n/1/), 139 entries included *artificial intelligence*, *ChatGPT*, or another related term in its title, abstract, or as a keyword. In addition, three pre-conference workshops focused on AI and a new special-interest group about genAI was launched. Overall, there was an ongoing buzz about genAI at the conference.

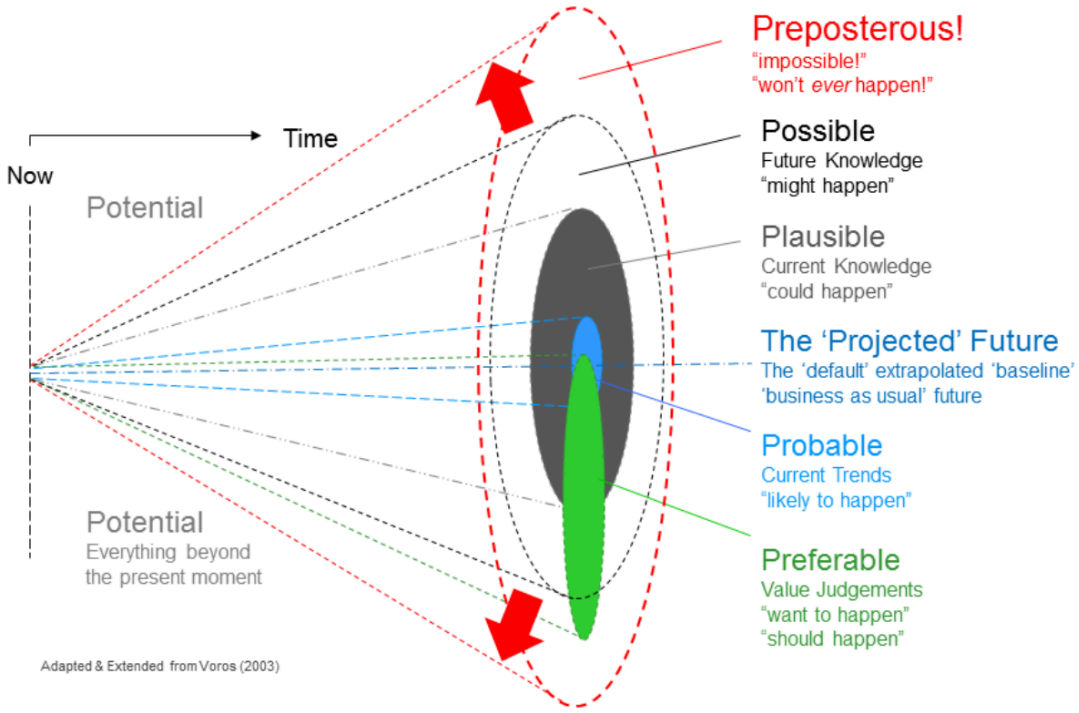
Leaving the conference and returning to my university, conversations about genAI continue, and shifts are starting to happen. Theoretical ideas of "what could be" with genAI for teaching and research are becoming practical applications. To maximize its benefits, there is still a significant and immediage need for providing professional development, resources, and instructional strategies (Burns & Muscanell, 2024). We must also be ever vigilant about genAI's ethical components (e.g., data privacy, algorithmic biases, profit motives, plagiarism), to advocate that the technology benefits society and all people.

It is within this context that I argue we must converge and then diverge. By *converge*, we must collectively recognize that genAI is going to impact our teaching, research, and long-term student learning outcomes. While there may be late adopters and even those resistant to the technology itself, the majority of us will interface and integrate genAI into our work. Then, to *diverge*, this is where we must think about the type(s) of future(s) we want with genAI and how to advocate for it. We each live, work, and exist in our own contexts, and genAI will become more deeply integrated into those contexts. In response, we need to define how that happens and mitigate potential issues with implementation to support the benefits we can derive from the techn9ology. To that end, I will next share a model I use to think about genAI's future in teaching and learning.

Many years ago, a colleague introduced me to *The Future Cones* (figure 1), a theoretical framework for making predictions about what could be in the future. As explained by Voros (2017, 2003), the Future Cones is a way to project into the future, and each cone represents a different type of future.

Figure 1

The Future Cones



Adopted based on Voros (2003, 2017)

- "Business-as-usual" cone: Represents a future where nothing significantly changes. The present becomes the future, and this cone serves as a baseline, with the others branching from it.

- "Probable" cone: A future that will likely happen, based on current patterns and themes.

- "Plausible" cone: A future that could happen, but it is not as likely as the probable future.

- "Possible" cone: A future that is less probable than the prior futures, but there is a chance that it can still happen.

- "Preposterous" cone: A future that is very unlikely to happen.

- "Preferable" cone: A future we envision as being ideal for ourselves. It is what we want to happen.

When making predictions, time is the key considerations. With the *Future Cones* being in the present, the further in the future the predictions are made, the cones become wider, which represents that a larger range of possibilities exists the more we glimpse into the future.

In close, I urge each of us to think about the futures we see for ourselves, our students, our research, and our communities as we engage with genAI. Our research provides us with a voice to communicate those futures, and I encourage our Society to use it.

Speak out against the problematic futures.

Advocate for those futures that benefit us all.

Ethically experiment with genAI in your classroom, laboratory, and community.

Document your usage.

Report your findings.

Talk about it with your colleagues and students.

As we do, let's converge again, at SITE 2026 in Orlando, Florida, and continue our community of learning with and from each other.

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EMBODIED LEARNING IN A MIXED-REALITY ENVIRONMENT: EXAMINATION OF STUDENT EMBODIMENT

Kyungbin Kwon
Indiana University, USA
kwonkyu@indiana.edu

Keunjae Kim
Indiana University, USA

Minhwi Seo
Indiana University, USA

Hyojung Kim
Indiana University, USA

Thomas A. Brush
Indiana University, USA

Abstract. This study investigates the effects of embodied learning experiences in learning abstract concepts, such as computational thinking (CT), among young learners. Specifically, it examines whether the benefits of embodied learning can be replicated within a mixed-reality setting, where students engage with virtual objects to perform CT tasks. A group of 10 first-grade students from an elementary school participated, engaging in embodied learning activities followed by assessments in CT. Through the analysis of video recordings, it was observed that participants could effectively articulate CT concepts, including the understanding of programming code meanings and their sequences, through their bodily movements. The congruence between students' bodily movement and CT concepts was found to be advantageous for their comprehension. However, the study also noted instances of incongruent movements that did not align with the intended CT concepts, which attracted researchers' attentions. The study identified that two distinct types of embodiments manifested in the mixed-reality environment, which shed light on the nuanced dynamics of embodied learning in the context of CT education.

Keywords. Embodied Learning, Mixed Reality, Computational Thinking (CT), Student Embodiment

Introduction

Embodied learning is a pedagogical approach emphasizing the crucial role of the body in the learning process based on the concept of embodied cognition, which suggests that human cognition is fundamentally rooted in our bodily interactions with the world (Barsalou, 2008). This perspective posits that learning encompasses not only cognitive but also physical, emotional, and social dimensions (Glenberg, 2008; Lakoff, 2012). It underscores the significance of bodily actions in enhancing conceptual understanding and problem-solving abilities. Engaging in activities – such as movement, gestures, expressions, and interactions – is believed to deepen learners' conceptual understanding by grounding cognition in their bodily actions or physical environments (Alibali & Nathan, 2012; Hostetter & Alibali, 2008).

Embodied learning expands its scope from physical environments to virtual ones, empowered by Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). AR overlays digital information onto the real world, enhancing the learning experience with interactive visual elements (Yu & Denham, 2023). VR creates a fully immersive digital environment, allowing students to explore and interact within entirely virtual settings (Agbo et al., 2023). MR combines elements of both AR and VR, integrating digital objects into the real world in ways that interact seamlessly with physical surroundings (Johnson-Glenberg et al., 2014). These technologies have great potential to enhance educational outcomes by providing immersive, interactive, and engaging learning experiences, which need further exploration in educational settings.

Embodied Learning for Computational Thinking

The incorporation of embodied learning into the pedagogical practices of computational thinking (CT) education gains more attention in K-12 settings, as it enhances engagement and improves conceptual understanding through active, physical participation (Kosmas et al., 2019). In teaching CT, educators are increasingly adopting hands-on, unplugged activities that promote students' physical engagement. Additionally, they introduce robot programming tasks, allowing students to apply what they have learned from physical activities directly into their programming projects (Bell et al., 2012; Kopcha et al., 2021; Kwon et al., 2022). This approach of incorporating bodily movements has been shown to significantly enhance students' understanding and mastery of CT concepts (Kwon et al., 2022). Furthermore, combining these physical actions with tangible learning tools and interactive technology, like robots and block-based coding platforms, has proven to build up students' enthusiasm and engagement with the subject matter (Bers et al., 2014; Fofang et al., 2021; Kim & Kwon, 2024). In this context, we examined the impact of embodied learning experiences on developing CT skills among elementary students (Kwon et al., 2022). The findings highlighted a notable improvement in students' CT and spatial reasoning abilities, without any gender differences in outcomes or attitudes, aligning with previous research that emphasizes the value of sensorimotor experiences in comprehending abstract STEM concepts (Zhong et al., 2023).

Embodied Learning in Virtual Contexts

The evolution of technology has broadened the scope of embodied learning to include virtual spaces, which are computer-generated environments that simulate real or imagined settings. Within these virtual spaces, students interact with objects, such as digital avatars, 3D models, and interactive simulations. These interactions are accompanied by immediate feedback, which can include visual cues, auditory signals, and real-time performance metrics, enhancing the immersive learning experience (Agbo et al., 2023). Recent studies affirm the benefits of embodied learning in these virtual or mixed-reality environments (Lindgren & Johnson-Glenberg, 2013; Lindgren et al., 2016; Oyelere et al., 2023; Yu & Denham, 2023). However, significant gaps remain in

understanding the effects of virtual embodied learning particularly regarding its long-term impact on cognitive and social development, best practice for classroom implementation, and equitable approaches for underrepresented students (Pellas et al., 2020).

Researchers argue that the impact of embodied learning varies with the degree of embodiment, suggesting a spectrum from superficial to profound embodied experiences. Skulmowski and Rey (2018) differentiated between merely incidental embodiment, where actions and cognitive processes are not related, and deeply integrated embodiment, which links learning tasks (cognitive processes) with intended actions (embodiment). Johnson-Glenberg et al. (2014) also emphasized the importance of gestural congruency in embodied learning, highlighting the relevance of an action mapping onto the content to be learned. Considering these suggestions, examining students' embodied learning experiences in a mixed reality setting, where virtual spaces can affect how students interact with simulated environments, can provide valuable insights into the literature. In particular, a deeper understanding of embodied learning mechanisms in virtual contexts can identify effective learning methods and suggest instructional design principles for creating impactful embodied learning experiences.

A notable challenge in existing research is its focus on short-term retention rather than long-term performance, and the implementation of embodied learning over limited periods. For embodied learning experiences to be meaningful, learners need ample practice to associate actions with concepts (Xu et al., 2022). A lack of sufficient practice in embodiment may result in a superficial understanding of concepts, thus impeding the application of acquired skills to problem-solving tasks.

Differences in utilizing embodiment among students play a critical role in the design and implementation of embodied learning activities. For instance, when students are not accustomed to expressing programming codes through bodily movement, significant variations in the adoption of such activities have been noted (Kwon et al., 2024). While engaging in embodied learning activities, students often use their bodies and learning environments to express abstract concepts or reasoning according to their perception and understanding, which involve individual differences in their embodiment (Kopcha et al., 2021; Manches et al., 2020). Therefore, to effectively leverage embodied experiences for every student, it is essential to acknowledge the diverse ways students engage in these activities.

Research Purpose

Despite the increasing number of studies on embodied learning across various settings, there remains a scarcity of research examining its multifaceted impacts based on the learning environments, types of embodiments, and learning performance. Given the current state of literature, this study aims to explore students' embodied learning behaviors within a mixed-reality environment. This will contribute to a more comprehensive understanding of embodied learning in education. The following research questions guide this study:

1. What types of embodiments do students demonstrate while practicing CT tasks in a mixed-reality learning environment?
2. How are the types of embodiments congruent with CT concepts?
3. How do embodied learning experiences affect students' CT problem-solving performance?

To frame this study, the next sections will discuss the methods used to collect and analyze data followed by the results and their implications for future practice.

Method

Participants

10 first-graders from a public elementary school in the Midwestern United States were recruited for this study using convenience sampling. Assent from the participants and consent from their parents/guardians was obtained before the intervention. None of the participants had experience with MR and did not learn CT in the contexts.

Learning Context

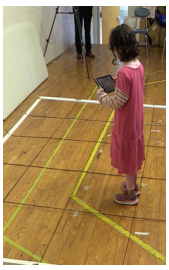
In this study, we developed a MR learning environment designed to facilitate the understanding and application of CT concepts, specifically focused on symbols and sequences (see Figure 1-a). Symbols represented elements of a programming language that indicate specific actions for a robot, while sequences referred to the organized arrangement of these symbols in a specific order to achieve desired outcomes. For CT tasks, students were guided to find appropriate paths to complete missions by moving a robot along with utilizing symbols and sequences. Within this environment, students navigated a chessboard-like arena, aiming to complete CT tasks through a strategic movement in an area of 92 square feet that has been outlined in a five-by-five grid. Each grid cell served a dual purpose: it defined the coordinated positions of an agent and various objects and it acted as a stage for the students to execute movements—either advancing forward or backward, or turning right or left at 90° angles—emulating robotic actions to navigate towards a designated goal (see Figure 1-b). AR technology was employed to superimpose virtual objects at the center of each grid cell, with these objects serving as mission items to be collected, obstacles to be circumvented, or destinations to be reached. Figure 1-a illustrates the virtual objects selected to make the learning scenario more engaging, specifically by presenting a dinosaur theme. This AR setup was responsive to the students' physical movements across the grid, offering immediate feedback based on their positional coordination within the board.

The system introduced four key symbols to represent movement directions: ⬆️ for Move Forward, ⬇️ for Move Backward, ➡️ for Turn Right, and ⬅️ for Turn Left. These symbols were displayed on the students' handheld tablet screens and linked directly to their physical movements. For example, advancing towards the next grid cell triggered the display of the Move Forward symbol, accompanied by a verbal cue, "You just moved forward." As students navigated the grid, executing various movements and turns, the sequence of symbols corresponding to their actions was dynamically listed at the bottom of their screen, visually representing the accumulated sequence of movements.

Figure 1

Virtual Objects Displayed on a Tablet (a) and The Physical Environment Where the Student Moved (b)

(a)


(b)

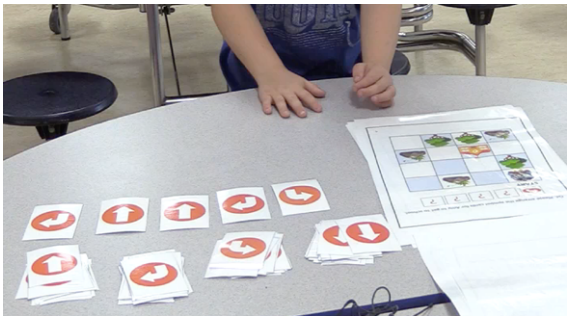
Research Data

This study collected three types of research data: video recordings of students' embodied learning in the mixed-reality environment, CT tests, and post-intervention interviews. Each student's embodied learning was recorded for approximately 30 minutes using two cameras alongside screen captures of their interactions with virtual objects on the tablet. The CT assessment comprised eight items designed to evaluate students' comprehension of meaning of symbols and their ability to organize these symbols to execute CT tasks, focusing on sequences. During the assessment, a researcher presented the questions sequentially, and students responded by physically manipulating symbol cards as appropriate. These responses were documented through video recording. Following the completion of the CT tests, interviews were conducted with the students to explore their learning experiences and self-assessed confidence in CT practices.

Figure 2

Sample Question (A) and Its Solution of a Student (B)

(a)


(b)

Procedure

The teacher introduced the study's objectives and secured informed consent as well as assent from participants who voluntarily agreed to participate in the research. Within a regular school day, students were escorted to a designated research site to engage in embodied learning activities within a mixed-reality environment. Each student, with the assistance of two of us, independently undertook CT tasks. Utilizing a hand-held tablet, students navigated the MR learning environment, which involved collecting specific items, avoiding obstacles, and ultimately reaching a predetermined destination. The MR application provided immediate feedback, including symbols representing each movement, a cumulative sequence of these symbols, and directional guidance or warnings concerning mission items or obstacles encountered. This MR feature offered participants a first-person perspective of the CT tasks, effectively merging their bodily movements with virtual symbols and sequences to achieve the set goal. This integration served as the primary learning objective of the intervention. Following the embodied learning experience, students were administered CT tests and subsequently participated in the interview. Each of these activities was conducted on a one-on-one basis.

Analysis

We adopted thematic analysis to examine students' learning experiences in the mixed reality learning context. To ensure trustworthiness, we followed the iterative and reflective phases of thematic analysis (Nowell et al., 2017) by (1) familiarizing ourselves with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report. We employed an inductive approach to understand learning experiences,

relying primarily on the data rather than a theoretical framework (Braun & Clarke, 2006). Given the limited number of participants, students' performance on CT tests was analyzed statistically to show learning gains without testing a hypothesis.

Findings

The study analyzed video recordings from a MR setting to explore how learners embodied and enacted CT concepts through their physical actions. Two main themes were identified, indicating that students demonstrated both congruent and incongruent embodiment. Congruent embodiment referred to students' actions that aligned with the CT concepts they were learning, while incongruent embodiment did not.

The findings reveal that, in most scenarios, students successfully mapped their bodily movements to CT concepts, showcasing a congruent embodiment. This congruence not only reflects a profound comprehension and application of CT principles through physical interaction within the mixed-reality context but also underscores the integral role of embodiment in the learning process. Furthermore, with increased participation in embodied learning activities, students exhibited a marked improvement in the congruence of their embodiment. This suggests that repeated practice in such an immersive environment enhances the natural and intuitive integration of CT concepts into physical actions.

However, the study also documented instances of incongruent embodiment, where students' movements did not correspond with the anticipated CT concepts. For example, some students moved sideways instead of executing a turn followed by a linear advancement, or they moved diagonally towards an adjacent cell rather than performing these actions sequentially (e.g., moving forward, turning, and then moving forward). These occurrences suggest the challenges in aligning students' intuitive or habitual movements with structured actions to express CT concepts, revealing a gap between natural behaviors and the planned embodiment of CT concepts.

In the subsequent section, we examine the nuances of these observations by categorizing the types of embodiments. This classification aims to provide a clearer understanding of how embodied learning in mixed-reality environments can both facilitate and challenge the acquisition of CT concepts.

Congruent Embodiment

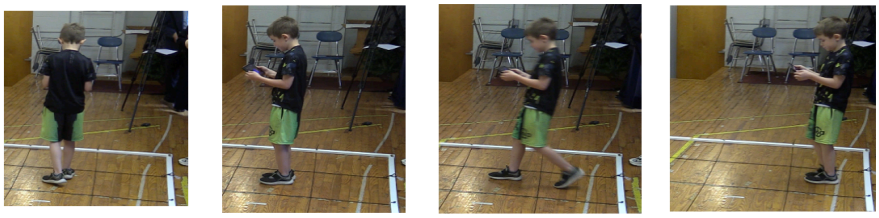
In this study, we adopted a unique approach to map physical movements and programming concepts, guiding students to “move like a robot” through four specific actions: Move Forward, Move Backward, Turn Right, and Turn Left. This deliberate restriction of movements aimed to immerse students in an experience that parallels programming tasks, engaging them with the symbolic systems that facilitate human-computer interaction. Thus, the instructional objectives were twofold: to grasp the underlying symbol system integral to programming and to apply this understanding in executing CT tasks. The rationale behind instructing students to perform these four actions was to mimic the basic commands in programming, thereby deepening their comprehension of CT concepts through physical embodiment.

Throughout the study, in most scenarios, students adeptly navigated the mixed-reality environment by adhering to the predefined actions. A closer examination of their behavior unveiled a progressive enhancement in their embodiment of these concepts. For instance, initially, one student cautiously took several steps towards the front cell, embodying a careful Move Forward action. This was acknowledged by the application as "one" Move Forward action, with the student

receiving dual-mode feedback: a visual symbol and an auditory confirmation ("You just moved forward"). As the practice sessions advanced, the same student confidently strode to the next cell in a single motion, showcasing a more sophisticated and intuitive understanding of the symbol for the Move Forward action (see Figure 3).

Figure 3

A Student Moved Forward by One Step and Turned the Right Way which Represents Two Symbols: Move Forward and Turn Right (See From Right To Left)



During the CT tasks, students exhibited proficiency in the debugging process when they needed to correct their movements. For instance, one student encountered an obstacle and promptly received feedback via the application. In response, the student navigated backward and explored alternative pathways around the obstacle. Upon selecting a new route, the student adjusted his body movements in accordance with the learned embodied CT. This exemplifies the embodied CT practices the students experienced in the mixed-reality environment.

Incongruent Embodiment

We observed instances of incongruent embodiment among students, wherein their physical actions did not align with the CT concepts intended to be mastered. Analysis of these occurrences suggests that students often demonstrated incongruent embodiment when they focused solely on completing the CT tasks, disregarding the intended embodied rules, such as moving like a robot using four symbols. The most common cases of incongruent embodiment were noted when students moved intuitively, akin to movements in natural settings. Four typical types of incongruent embodiment were identified:

Moving sideways: For instance, when facing north and attempting to move one step east, students might naturally opt for a side step to the east, which is a common movement in daily life. However, in the MR learning context, this movement was not permitted because it did not represent the robot's movement. Instead, the correct movement would involve a combination of two steps: turning to the east and then moving forward. We observed that students sometimes moved sideways when transitioning to the next cell on their left or right, without intentionally adhering to the embodied rule (see Figure 4-a). This type of movement deviated from the symbol system used in their embodied learning.

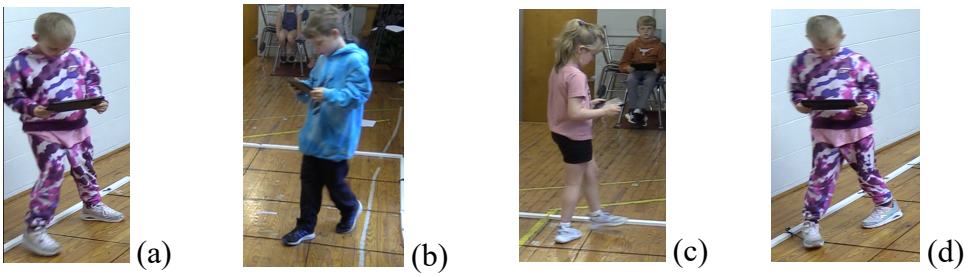
Diagonal movement: When students identified a target in a cell diagonally positioned, they tended to move diagonally towards it instead of taking multiple sequential steps. While diagonal movement is natural and efficient in daily life, in the embodied learning scenario, students were expected to execute multiple steps (e.g., Move Forward, Turn Right, Move Forward) to reach a diagonal cell. We noted that students exhibited diagonal movement when rushing towards a target while overlooking the embodied rule (see Figure 4-b).

Combining multiple steps into one: In contexts similar to diagonal movement, students sometimes combined forward movement with an immediate right turn. While this could be interpreted as efficient performance, we classified it as incongruent embodiment because it did not adhere to the sequence of actions (Turn Right and Move Forward), instead reflecting intuitive movement (see Figure 4-c and 4-d).

Taking small steps representing one symbol: Students carefully moved toward a path by taking small steps, which were identified as incongruent embodiment. In instances where students stopped in the center of a cell before taking the next actions, we identified it as congruent embodiment, even though it involved taking multiple small steps. However, taking small actions toward a sequence of steps was identified as incongruent embodiment because it did not represent the sequential order of symbols. Students demonstrated this type of action when they were not confident with their movement and/or needed to explore a route toward a goal.
These observations highlight the importance of aligning students' physical actions with the intended embodied rules during CT tasks. Incongruent embodiment appeared not to benefit students' understanding of CT concepts and their ability to practice them during CT tasks.

Figure 4

Incongruent Embodiments: Moving Sideways (A), Diagonal Movement (B), and Combining Multiple Steps into One (C And D)



Coordination of Virtual and Physical Information

As students navigated within the MR environment, they were required to integrate virtual information presented by the application with the physical environment around them. In the majority of instances, students effortlessly coordinated between these dual sources of information and engaged with virtual objects without difficulty. This observation indicates that the MR environment naturally supported intuitive interactions, enabling students to effectively process and act upon information from both virtual and physical spaces.

Nonetheless, an interesting behavior was noted concerning students' spatial awareness and safety checks. When moving backwards, students often chose to turn their heads to visually confirm the space behind them, rather than relying on the tablet's display. This behavior suggests a preference for direct physical verification over virtual assistance, particularly in situations where students felt unsure or perceived a need for increased safety. It also highlights a reliance on physical cues for navigation and decision-making in uncertain or potentially unsafe situations within the mixed-reality context.

Performance on CT Tasks

The analysis of performance test results over two assessment periods revealed a nuanced yet overall positive shift in students' comprehension of CT, specifically in understanding symbols and

sequences. The increase in the mean scores from the first test (mean = 8.75, SD = 15.65) to the second test (mean = 18.75, SD = 25.85) suggests a significant improvement in the students' comprehension and application of CT concepts. This improvement reflects students' enhanced ability to identify code meanings, predict outcomes, and logically arrange codes.
However, despite the positive trend, the data also underscores the substantial individual differences in learning outcomes. While some students have made significant advancements, others have not shown noticeable progress, indicated by the increase in the standard deviation from the first to the second test. This variation suggests that while the embodied learning experiences might be effective for some students, they might not address the learning needs or styles of all students equally.

This result suggests the necessity for further investigation into the factors contributing to these individual differences. Specifically, future research should consider exploring the impact of embodied learning experiences on CT performance. It is hypothesized that students who exhibit more congruent embodiment with CT concepts might show enhanced performance, or conversely, a lack of congruence could hinder learning outcomes. Understanding these dynamics can inform the development of more effective, inclusive teaching strategies tailored to diverse student needs.

Discussion and Conclusion

In this study, we explored how students demonstrated embodiment while expressing CT concepts in problem-solving contexts where a mixed-reality provided immersive experiences. The analysis of student embodiment identified two distinct types: congruent and incongruent embodiments. The study demonstrates how congruent embodiment significantly helps students' comprehension of abstract CT concepts through physically mapping movements to programming concepts. By engaging students in a physical representation of programming tasks, the study facilitated an immersive learning experience and enabled students to internalize the meaning of symbols and sequences underlying programming. As they manipulated and interacted with physical and virtual objects, they began to associate their actions with abstract ideas of symbols and sequences. By situating abstract concepts of CT in a concrete context of task-finding with AR, students gained a deeper understanding. This finding aligned with the previous studies that embodied approaches within a MR context enhanced students' understanding of CT and programming by grounding those ideas with bodily movements and hands-on experiences (Kwon et al., 2022; Lindgren et al., 2016).

Some students showed incongruent embodiments during the tasks. One of the possible reasons could be students' cognitive load. MR environments can sometimes impose a high cognitive load on learners, especially young ones (Skulmowski & Rey, 2018). For instance, managing the physical interaction with the virtual elements, checking the physical spaces, and simultaneously processing abstract concepts like CT can be challenging. This cognitive overload can lead to mistakes in bodily movements that do not align with the intended learning objectives (Loup-Escande et al., 2017). Thus, it is critical for educators to design tailored instruction with interactive learning environments, particularly for young students. This finding is consistent with the studies that emphasized bridging the gap of cognitive load within the mixed-reality context by designing age-appropriate interventions (Lai et al., 2019).

This study calls for follow-up research to investigate individual differences in embodiment and the causal relationship between types of embodiments and learning performance. Several learner factors, such as prior knowledge, modal preferences, cognitive development, and learning strategies, affect the outcomes of embodied learning (Deininger et al., 2012; Kwon et al., 2022; Zhong et al., 2023). As shown in the current study, differences in embodiment among individual students can influence the dynamics of embodied learning settings, necessitating further

investigation on this issue. The analysis of student embodiment also requires additional research into the causal impacts of the types and depth of embodiment on student learning. Although there is a growing body of research suggesting the positive impacts of embodied learning, there remains a lack of studies identifying productive and meaningful embodiments that would provide insights into designing effective embodied learning environments and instruction (Duijzer et al., 2019).

Limitations

While this study provides valuable insights into the effects of embodied learning in a MR environment on CT among young learners, several limitations should be acknowledged. The findings are limited by the small sample size of ten first-grade students, which affects generalizability. Additionally, the novelty of the mixed-reality environment and limited time for practice might impose a high cognitive load on the students, potentially affecting their learning performance and understanding. Future research should address these issues by including a larger, more diverse sample and exploring long-term effects.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant #2048989.

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CULTIVATING A GEO-SUSTAINABLE MINDSET IN HIGH SCHOOL CHEMISTRY STUDENTS USING GEOGRAPHIC INFORMATION SYSTEMS

Curby Alexander, PhD
Texas Christian University, USA
curby.alexander@tcu.edu

Molly Weinburgh, PhD
Texas Christian University, USA

Kristen Brown, PhD
Texas Christian University, USA

Abstract. While smartphones are familiar in high schools, their intricate material composition and far-reaching geographical footprint remain largely unexplored. This research explores how educators can leverage ArcGIS, a geospatial software tool, to bridge the gap between theoretical understanding and real-world consequences. The paper details a collaborative project between researchers and teachers to integrate location-based learning into the curriculum. One such project involved a teacher using geographic information systems to guide students in exploring the global impact of smartphones. This approach fostered critical thinking and environmental awareness, equipping students with vital knowledge about the materials behind everyday technology. By harnessing the power of geospatial tools, educators can cultivate a generation of "geo-sustainable" thinkers prepared to navigate the complex life cycle of digital devices – from extraction to disposal – in an environmentally responsible manner. This paper delves into the project methodology, the application of geospatial technology, and the broader implications for future research in this domain.

Keywords. Geographic Information Systems (GIS), Geo-Sustainable education, High school Chemistry, ArcGIS, Smartphone Materials

Introduction

Across the tapestry of American high schools, one ubiquitous object reigns supreme: the smartphone (Sutisna et al., 2020). These compact computers have revolutionized communication, information access, and entertainment. However, beneath their sleek exteriors lies a hidden world of materials and elements, extracted from across the globe. To grasp the true impact of smartphones on society and the environment, we must delve deeper and explore the building blocks that bring these devices to life (Bookhagen et al., 2020).

In our globalized world, educators face the challenge of fostering critical thinking about technologies deeply integrated into our lives (Chalup, 2024). This paper proposes ArcGIS, a geospatial software tool, as a key to unlocking a deeper understanding of smartphones – devices students use daily yet often take for granted. By integrating geographic information systems (GIS), educators can cultivate a "geo-sustainable" mindset. Students will not only explore the origins and impacts of these devices but also grapple with the future: how can we develop, manufacture, distribute, and dispose of them responsibly (Koppelaar et al., 2023)? This approach bridges the gap between the abstract concept of a smartphone's components and the real-world geography that shapes their impact on individuals, society, and the environment.

ArcGIS is a powerful software developed by Esri that enables users to analyze, visualize, and interpret spatial data. It plays a crucial role in various fields such as urban planning, environmental management, and public health by providing tools to create detailed maps, analyze spatial relationships, and model geographic phenomena. By integrating and analyzing diverse datasets, ArcGIS helps users in spatial analysis and data visualization. In education, ArcGIS holds immense potential for pedagogical tool, hands-on, and inquiry-based learning, but it remains limited in many schools. This paper demonstrates the technologies unique affordances for education.

This paper details a collaborative project involving researchers from three universities and teachers across seven high schools aimed to bridge this gap. The project focused on integrating geospatial concepts and strategies into the curriculum using the ArcGIS suite of tools, fostering students' spatial reasoning and awareness in various disciplines. One captivating example involved a teacher using GIS to guide students in exploring the hidden global impact of their smartphones. This approach not only equipped students with vital knowledge regarding the materials behind the everyday technology they use, but it also fostered critical thinking skills. Students gained a deeper understanding of the environmental and ethical considerations surrounding society's consumption of technology. This case study also serves as a testament to the power of ArcGIS in cultivating a generation of responsible consumers who are aware of the geographical footprint hidden within their devices.

Review of Literature

In recent years, as society has focused more on environmental sustainability, some teachers and researchers have explored the intersection of technology and its environmental impact, examining how these two domains both impact the environment and can be used to promote an environmentally sustainable mindset among students.

Becker and Dreesmann (2023) investigated the potential of computer simulations in German high school biology classes for helping students understand environment issues. Their research findings indicated computer simulations as a student-centered method can be profitable for students, increasing their understanding of environmental issues and combating their lack of botanical knowledge. Buchanan, Pressick-Kilborn, and Maher (2018) critically explored innovative, formal

and informal learning practices with technology in environmental education initiatives among schools, families and communities. Their study included the use of digital technologies, including videoconferencing, mobile apps and virtual and augmented realities, to provide new ways of engaging students in environmental stewardship. Similarly, Napal, Mendióroz-Lacambra and Peñalva (2020) researched the application of information technology to help students develop environmental sustainability competency. The findings of these two studies suggest the potential of geospatial technologies to pique student interest, enable learners to capture experiences of local and distal environments, to collect data, and share findings with broader audiences.

Several additional studies have explored the use of GIS technology for teaching environmental sustainability. As early as 2004, Bednarz was discussing the affordances and constraints of GIS for teaching about the environment, environmental issues, and sustainability. Aguilar et al. (2022) developed a curriculum using GIS-driven visualizations to teach sustainability concepts to students at various levels. Landenberger et al. (2006) employed the remote sensing capabilities of GIS to develop land-cover biology and hydrology investigations, and their findings suggest that GIS was an effective tool for helping students understand how terrestrial and aquatic systems interact, and it strengthened their knowledge about the link between science and land use policy. More recently, Carrigan et al. (2019) employed the field-based data collection capabilities of ArcGIS to facilitate student investigations of the intersection between ground temperature, surface type, tree cover, and urban heat. Students used infrared thermometers to collect and map data about ground temperatures around their school. The GIS technology enabled them to create visualizations showing the campus "hot spots," and they presented their findings to the school community to advocate for planting trees in critical areas around the school campus.

Theoretical Framework

The Technological Pedagogical Content Knowledge (TPACK) framework serves as the guiding theoretical model for this study, underpinning the integration of geospatial technology in high school curricula. TPACK is a comprehensive framework that articulates the interrelationship between three primary forms of knowledge: technological, pedagogical, and content knowledge (Koehler & Mishra, 2009). This model is instrumental in understanding how teachers can effectively leverage the affordances of technology in their teaching practices to enhance both content learning and pedagogical strategies (Mishra & Koehler, 2006).

Technological Knowledge (TK) refers to the educators' proficiency with technology tools such as geospatial, immersive, or media production technologies. Proficiency with technology can include understanding the features of the software and hardware, knowing how to troubleshoot issues, and using the technology effectively. Pedagogical Knowledge (PK) involves the strategies and methods employed by the teacher to facilitate learning. This knowledge domain includes developing a repertoire of teaching strategies (e.g., direct instruction, project-based learning, concept teaching, inquiry-based learning, etc.), understanding developmentally appropriate practices, and classroom management strategies. Content Knowledge (CK) pertains to knowledge about the subject matter being taught. Teachers with well-developed content knowledge understand the nature of their discipline, the structure of the knowledge base, learning progressions, and common misconceptions particular to a certain area of content knowledge. Having a solid grasp on content knowledge allows teachers to plan instruction in an effective and meaningful way.

Context

This project tackles the critical issue of smartphone element composition and its environmental impact. By exploring the potential of ArcGIS software as a tool for educators and

proposing a novel strategy for integrating it into high school classrooms, this instructional unit invited students into the hidden world masked by digital devices, fostering both geospatial awareness and responsible environmental practices (Fairfield, 2018).

The project was implemented within a Science, Technology, Engineering, and Mathematics (STEM) academy located in a large metropolitan area of the Southwestern United States. The researchers' central aim was to empower students to connect the elements found in their smartphones to the broader geographical and environmental implications of the digital device production process. The following sections detail the project itself and the steps undertaken for its implementation.

This project, designed by a high school chemistry teacher, aimed to cultivate student comprehension of the chemical composition of their personal digital devices and their broader societal and environmental impact. The participants included 93 first-year high school students enrolled in the STEM academy (Table 1). Students did their own research to identify the geographical origins of the raw materials vital to smartphone production. This investigation delved into the global nature of the technology manufacturing industry, specifically focusing on the locations of mining and extraction for elements like rare earth metals, lithium, and cobalt.

Table 1

Demographic Characteristics of Participants

Sample Characteristics	**n**	**%**
Gender		
Male	38	40.9
Female	55	59.1
Race/Ethnicity		
American Indian or Alaska Native	0	0.0
Asian	2	2.2
Black or African American	14	15.0
Hispanic or Latino	40	43.0
Middle Eastern or North African	2	2.2
Native Hawaiian or Pacific Islander	0	0.0
White	35	37.6

Note: N = 93 for Gender; N = 93 for Race/Ethnicity. Percentages may not sum to 100 due to rounding.

The initial phase of the research tasked students with investigating the processes behind element extraction, refinement, and distribution of smartphones. This encompassed exploration of mining techniques employed to acquire the materials, the refinement processes required to render

them suitable for technological applications, and the distribution networks responsible for transporting these resources to global manufacturing centers. Furthermore, the study expanded its scope to encompass the environmental ramifications associated with the entire life cycle of smartphones, from the initial extraction of raw materials to the manufacturing process, product use, and eventual disposal. This holistic approach ensured students gained a comprehensive understanding of the environmental consequences associated with these digital devices.

To complement their investigation into mining and extraction techniques for individual elements, students were tasked with analyzing how technology companies address the environmental damage caused by production and disposal waste due to the production of smartphones. This analysis centered on understanding the recycling, reuse, and responsible disposal practices implemented by manufacturers.

The project culminated in an exploration of labor laws and practices within the countries responsible for element production or device manufacturing. This final phase involved a critical examination of issues such as working conditions, worker rights, and the broader social implications associated with element extraction and processing. This multifaceted approach ensured students gained a nuanced understanding of the ethical dimensions embedded within the entire smartphone life cycle.

Methodology

The study employed thematic analysis as its primary methodological approach to explore and understand the nuanced perceptions and experiences of high school students and educators regarding the integration of geospatial technology in the curriculum.

Data Collection

The data for this study consisted of 93 student-generated narratives about the production practices and environmental impacts of smartphone manufacturing taken from the ArcGIS StoryMaps. These narratives were collected as part of an integrated physics and chemistry high school course. Students researched their assigned chemical element found in smartphones, and they entered their findings in a Survey123 form integrated with ArcGIS. Each student response was geocoded and associated with that particular geographic location on a map. In addition to the name and geolocation of their chemical element, students were asked to include an image of the mining facility. They researched the following prompts and entered their data in the form:

1. *Discuss why this production or mine is important*
2. *Briefly explain the steps required to mine/ produce this chemical?*

All the student responses were aggregated on the same map, and the researchers were able to access their responses directly through the map and by exporting them into a spreadsheet. The aggregated student responses and map can be viewed at https://t.ly/1CrV9.

Data Analysis

The researchers employed a thematic analysis approach to investigate the student narratives (Braun & Clarke, 2012). This qualitative research method focuses on identifying, analyzing, and reporting patterns or themes within a dataset. The analysis unfolded in a series of steps. First, familiarization involved the researchers meticulously reading through all 93 narratives. This deep immersion allowed them to identify initial patterns and ideas within the data. Next, the researchers

generated initial codes and systematically coded emerging themes from the data, essentially organizing the narratives into meaningful groups. Subsequently, the researchers shifted their focus to searching for themes. They collated the various codes into potential overarching themes, aiming to capture significant elements of the data concerning smartphone production practices and environmental impacts. Finally, the analysis culminated in defining and naming themes. Analysis of these data has revealed the following themes.

Implementation

This project utilized a variety of geospatial tools. Students used ArcGIS software for each phase of the project, and the result was an interactive digital map along with StoryMaps where students could reflect about their learning.

For the learning process, students first conducted comprehensive research to identify the metals and minerals used in the manufacturing of smartphones. They sought information regarding the name of the element, its global sources, the methods employed for its extraction, and the significance of its geographical location. To streamline the data collection process, students utilized a Survey123 form, which integrates seamlessly with ArcGIS Online. Within this form, they recorded the details they had gathered about each element. This information was automatically synced to the class map, as depicted in Figure 1.

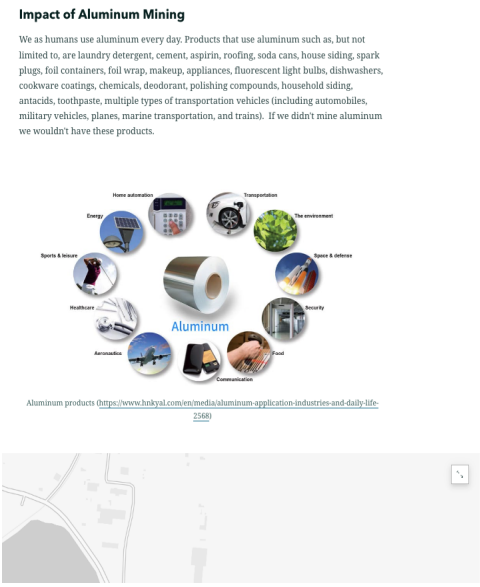
Figure 1

ArcGIS map of Student Research on Elements Found in Smartphones

Leveraging the capabilities of the ArcGIS platform, students next created interactive and informative ArcGIS StoryMaps (Figure 2). These StoryMaps served as a platform for the thoughtful integration of geographical data pinpointing the mining locations of each element. Functioning as a multimedia narrative, the StoryMaps allowed students to present a holistic analysis encompassing the multifaceted impact of each element. This analysis balanced both the positive and negative repercussions on the local economy, environment, technological advancement, and labor practices within the region of focus.

Figure 2

StoryMap with Student Reflections



The project's implementation phase proved to be a dynamic and engaging learning experience, fostering active student participation in the exploration of smartphone components. By harnessing the power of geospatial technology and fostering reflective storytelling, the project facilitated a deeper understanding of individual elements and equipped students with the critical skills necessary to analyze the broader global impact associated with smartphone production. This multifaceted approach fostered a deeper appreciation for the complexities of the technology industry and its associated environmental and societal considerations.

Results and Findings

In the following section, the results of the study are presented, highlighting the key findings that emerged from the data analysis. These findings provide insights into the relationship between student knowledge and understanding of the elements used to build a smartphone and the geospatial implications of extracting and refining those elements for consumer use.

First, through their research, students identified the importance of specific resources. Their responses highlighted the economic benefits, historical significance, and unique properties of these resources. Students emphasized the role of mined minerals in various aspects of their lives, from technology and infrastructure to everyday products. For example, one student identified the importance of uranium because “it is crucial for powering nuclear reactors, which provide electricity to communities in countries like Japan and the USA.” Another student stated, “Aluminum is widely used in the construction of aircraft, vehicles, and buildings. It is also used in everyday items like kitchen utensils and appliances,” and a third student made the following observation, “Boron is used in a variety of products, including glass, ceramics, and detergents. It is also essential in agriculture and as a fire retardant.”

Second, students were able to articulate the global impact of mining. Students discussed how mining activities have a global reach, impacting economies, trade, and even political power. They also mentioned specific countries and regions as major producers of certain resources. The responses highlighted the global nature of the mining industry, with minerals being transported and

traded across continents. Regarding economic impact, one student stated, “The Escondida Mine in Chile is the largest copper mine globally. Copper is essential for wiring, motors, plumbing, and electrical industries, making it a critical component of modern infrastructure and technology. The mine's production supports both local and global economies by providing essential materials for various industries.” Similarly, another student wrote, “The boron mine in California is the largest in the world, providing nearly half of the world's borates. This mine supports global agricultural, industrial, and household applications, demonstrating the extensive reach of boron mining on daily life and industry,” and a final stated, “The largest gold mine in Latin America, located in the Dominican Republic, significantly impacts the local and regional economy. It contributes to economic growth, employment, and sustainable development, benefiting neighboring countries through mutual prosperity.”

The third theme to emerge from this analysis was the environmental and societal impacts of mining these resources. Several responses acknowledged the environmental consequences of mining, such as the release of harmful chemicals or the depletion of natural resources (e.g., “Open-pit mining methods, such as those used in gold mining in the Dominican Republic, can lead to significant land disturbance and habitat destruction.”), and some responses extended to the social impacts, like job creation or cultural preservation (e.g., “The Eagle Mining Co. in California was restored to its 1870s condition to share the state's history, demonstrating efforts to preserve mining heritage.”). The responses also touched upon the environmental consequences of mining, such as deforestation, land degradation, and pollution. Some students express concern about sustainable mining practices. For example, one student made the following observation, “The petroleum refinery in California, with its large crude oil refining capacity of 363,000 barrels per day, likely contributes to air and water pollution.”

Fourth, student responses addressed the technological advancements shaping the mining industry, making it more efficient and allowing for the extraction of previously inaccessible resources. For example, students mentioned that advancements in mining equipment over the last several years have made the extraction of bauxite more efficient for mining companies worldwide. The Bayer Process, developed for aluminum mining, has made the process more expeditious. Students described various mining methods, including open-pit mining, underground mining, surface mining, and dredging, used for different minerals and depending on their depth and location. Students outlined detailed specific steps involved in mining different minerals, such as crushing, grinding, flotation, smelting, and refining. These responses also included discussions of the dangers associated with mining, including cave-ins, exposure to hazardous materials, and physical labor. As one student stated, “Uranium mining involves exposure to radioactive materials, which can pose significant health risks to miners. The process includes strip mining and underground mining, both of which can be hazardous due to the potential for cave-ins and the handling of radioactive ore,” and another wrote, “The mining of nickel sulfide involves crushing ores and using selective flotation, which can expose workers to hazardous chemicals and dust. The physical labor involved in mining and processing nickel sulfide can also be strenuous.” They mentioned protective equipment and safety precautions miners need to take. Students also voiced their concerns about child labor and unfair working conditions in some mining operations. They highlighted the use of machinery, explosives, and chemicals in these processes, and they raised concerns about the environmental and ethical implications of mining practices. Regarding the mining of iron in Australia, a student wrote, “The mining of iron ore contributes a large amount to air pollution, and the mining of iron ore also causes water pollution of heavy metals and acid that drains from the mines. This can affect the life of nearby animals and plant life. The pollution caused by these mines also lasts for a long after the mine is stopped. In the long run, this will severely damage the environment.”

A fifth theme was the historical context of mining in different regions of the world, discussing their role in ancient civilizations or major historical events. One student reported, “The Eagle Mining Co was part of the California Gold Rush in the 1800s, a major historical event that attracted thousands of people to the region in search of fortune. This gold rush significantly contributed to the economic development of California and the western United States.” Another student referenced the historical significance of coal mining near Chicago, “Coal mining in Chicago began in 1865 and lasted about a century. It played a crucial role in the city's development, providing essential resources for building and industrial activities.” Some responses mentioned the evolution of mining techniques over time, contrasting traditional methods with modern approaches (e.g., “Early gold mining relied on methods such as panning, sluicing, and placer mining, which involved manually separating gold from other materials in riverbeds and streams. Modern gold mining involves more sophisticated processes such as crushing, flotation, oxidation, and the use of cyanide for extraction.”). Some responses addressed the economic dependence of certain communities on mining activities. For instance, “The Karatau Mine in the Budenovskoye Uranium ore field in Kazakhstan is important for local jobs. Uranium mining supports the local economy by providing employment opportunities and contributing to the energy sector.”

Finally, students made personal connections to the mining industry by mentioning their own connections to mining, either through family members who work in the industry or their experiences visiting mines. For example, one student mentioned visiting the Eagle Mining Company in California, and another talked about having relatives who work in the oil and gas industry. This included students referencing steps they could take as consumers or advocates that demonstrate environmentally friendly practices and attitudes. One student referenced a refinery that, “manufactures cleaner-burning California Air Resources Board (CARB) gasoline and diesel fuel, as well as other conventional gasolines and petroleum products. This demonstrates a commitment to producing cleaner fuels and reducing environmental impact.”

Discussion and Implications

In today's world, characterized by rapid technological advancement and increasing environmental concerns, cultivating a geo-sustainable mindset among the next generation of students is paramount. This mindset goes beyond simply understanding environmental issues; it fosters a holistic perspective that considers the geographical, social, and economic implications of human activity on a global scale.

The learning experience explored in this study serves as a powerful example of how to cultivate critical thinking by leveraging TPACK. By integrating chemistry, geography, environmental science, and social studies, the project offered students an immersive and interdisciplinary exploration of smartphone production.

Technological Knowledge (TK) in the context of this study was identified in the educators' and students’ proficiency with ArcGIS, a sophisticated geospatial software tool. By leveraging ArcGIS, students were able to map the geographical and material journeys of smartphones. This enhanced students' understanding of the global impact of these devices, fostering a deeper engagement with the content. Pedagogical Knowledge (PK) involved the strategies and methods employed by the teacher to facilitate learning. In this project, the inquiry-based pedagogical approach encourages critical thinking, research and information literacy, and aggregating all the data into one map. Students were then able to combine geospatial data with other media into StoryMaps, such as text, video, and images, to communicate the journey of these various elements from the earth to the smartphone. Content Knowledge (CK) pertained to the subject matter being taught, which in this study included the material composition and geographical footprint of

smartphones. The integration of this content with geospatial tools provided a rich, interdisciplinary learning experience that connected science, technology, and environmental education. This approach not only enhanced students' content knowledge but also their ability to apply this knowledge in practical, meaningful ways.

Using TPACK, educators effectively combined technological tools with pedagogical strategies to deepen their students' content knowledge. It was not just about the elements on the periodic table, but rather, it was about where those elements are mined, the environmental impact of extraction, the complex global supply chains involved, and the ethical considerations surrounding labor practices. This multifaceted approach, facilitated by TPACK, allowed students to move beyond the sleek device in their pocket and delve into the intricate web of factors that contribute to its existence, thereby enhancing their critical thinking and understanding of the interconnected world.

Equipping students with a well-rounded understanding of the technology that defines their generation is crucial. Smartphones are ubiquitous, yet the hidden complexities behind their production often remain unexplored. Through the application of TPACK, this project enriched classroom learning and fostered a deeper appreciation for the broader global context in which technology operates. For example, teachers used interactive digital maps (technology) to help students visualize and understand the geographical origins of raw materials (content) used in smartphones, which facilitated their inquiry-based learning to be aggregated into a common map (pedagogy). Additionally, the StoryMaps platform allowed students to communicate their findings using a variety of media (technology and content) in a collaborative environment (pedagogy). Furthermore, by examining the human element in smartphone production through multimedia resources and real-world case studies (technology), the project fostered ethical awareness, encouraging students to consider the social implications of technological advancement.

Conclusion

In conclusion, this research paves the way for a more holistic approach to STEM education, one that cultivates not just technical skills, but also a generation of responsible and informed citizens who understand the interconnectedness of the planet and the impact of human actions on a global scale. This geo-sustainable mindset will be instrumental in navigating the challenges of the future and ensuring a more sustainable and equitable world for all.

Limitations

This study has several limitations that should be acknowledged. First, the data were collected from a single school, which limits the generalizability of the findings. The unique context and characteristics of this school may not reflect those of other schools, making it difficult to apply the results broadly. Additionally, all the students in the study were taught by the same teacher. This introduces a potential bias, as the teacher's specific instructional methods, personality, and interaction style could have influenced the students' responses and the quality of their work.

Furthermore, the study involved only one teacher and 93 students. While this sample size is relatively large for a qualitative study, the lack of diversity in the teaching staff means that the findings are based on a singular pedagogical approach. This limits the ability to explore how different teaching styles might impact student outcomes and thematic patterns.

Another limitation is the variability in the quality of student products. The wide range of quality in the student work could affect the reliability of the thematic analysis. High variability

might lead to an uneven representation of themes, as some themes might emerge more prominently due to the presence of high-quality submissions, while others could be underrepresented due to lower-quality work.

Lastly, qualitative thematic analysis inherently involves a degree of subjectivity in identifying and interpreting themes. While efforts were made to ensure rigorous and systematic coding, the findings are still influenced by the researchers' perspectives and biases. Future research could benefit from including multiple schools and teachers, employing a more diverse sample, and incorporating additional methods to triangulate the data and validate the themes identified.

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USING ITEM RESPONSE THEORY TO DESCRIBE QUANTITATIVE MEASURES OF TPACK

Ralph Saubern
Monash University, Australia
ralph.saubern@monash.edu

Daniel Urbach
Victorian Curriculum and Assessment Authority, Australia

Abstract. This paper proposes a potentially valuable use of item response theory to provide meaningful qualitative descriptions of quantitative measures of teachers' TPACK proficiency. While relatively unused in social science research, item response theory is a well-established measurement approach that has several advantages over classical test theory. Item response theory has featured in research using the Technological Pedagogical Content Knowledge (TPACK) framework, mainly for the purpose of establishing the validity of test instruments. This paper explores another key feature of item response theory – meaningful qualitative descriptions of quantitative test scores – and how it may be applied in TPACK related research. Using a Rasch analysis of a TPACK survey tool, the paper explores how teachers' quantitative scores on the survey can be used to describe their TPACK proficiency in qualitative terms.

Keywords. TPACK, Item Response Theory, Measurement

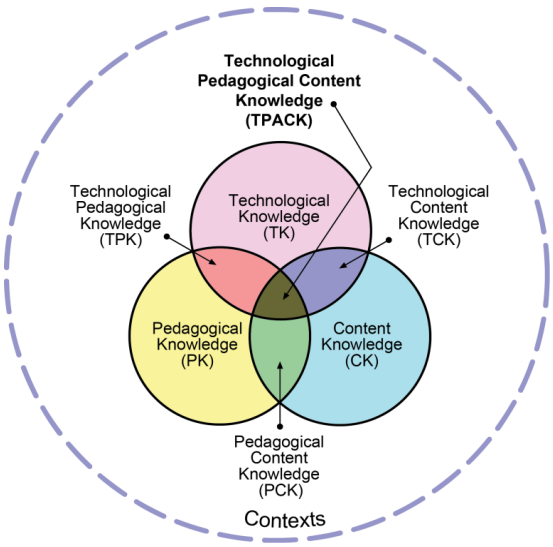
Introduction

The Technological Pedagogical and Content Knowledge (TPACK) framework (Koehler & Mishra, 2005) is a widely used framework for understanding and describing the professional knowledge base used to integrate technology in teaching and learning. The framework describes how this knowledge develops as a result of teachers integrating their knowledge of technology, pedagogy, and content (figure 1). Developed in the context of ongoing debates about the need to redesign teacher education programs to better facilitate teachers' knowledge development, the necessity to measure teachers' TPACK has resulted in the development of many hundreds of published instruments (Koehler et al., 2012). Noting the growing numbers of tools being developed to collect evidence of teachers' TPACK, Cavanagh and Koehler (2013) highlighted the importance of systematic approaches to validation.

Rasch modeling, which is a form of item response theory (IRT), is one approach for validating TPACK measurement instruments. While IRT is a well-established methodology and has a number of advantages over classical test theory (CTT), it is relatively unused in mainstream social science research (Foster et al., 2017; Bovaird & Embretson, 2008). In Rasch modeling, the relationship between the difficulty of an item and the ability of a person is modeled to construct a unidimensional, interval scale which describes a latent construct (Wilson, 2003; Wright & Masters, 1982). To construct a Rasch measurement scale, response data from a sample of test takers are analyzed and item parameters estimated. Through this process, the validity of the model is evaluated and, if the model fits and the item parameters hold, the resulting scale can be used as a measurement model. While these qualities of Rasch modeling have been useful in TPACK related research for establishing validity and exploring the qualities of measurement tools, other features of Rasch modeling have not been widely applied in published TPACK research. This paper explores one feature of Rasch modeling, the ability to meaningfully describe quantitative test scores in qualitative terms, and how it might be used to support greater understanding of teachers' developing knowledge of effective use of technology in teaching and learning.

Figure 1

Technological, Pedagogical and Content Knowledge (TPACK)[1]



[1] Reproduced by permission of the publisher, © 2012 by tpack.org

Rasch Modeling in TPACK Research

Studies employing Rasch modeling in TPACK-related research have used it mainly to establish validity and reliability and to provide suggestions for improvements to the measurement tools under examination (Bakar et al., 2019; Fütterer et al., 2023; Jamieson-Proctor et al., 2013; Pieters, 2019; Puspitasari et al., 2020; Singer, 2016). Jamieson-Proctor et al (2013) used Rasch analysis mainly to identify misfitting items in the survey and confirm the unidimensionality of the remaining items after misfitting items were removed. Singer (2016) used a Rasch analysis to determine whether test items were measuring the construct, to determine whether they were well matched to the respondents and to investigate the nature of the construct. Fùtterer et al (2023) used Rasch analysis to confirm the unidimensionality of the model and therefore provide confidence that teacher educators could use the overall score as an indicator of TPACK proficiency.

Saubern et al (2019) reported on the products of a partial credit model Rasch analysis, an extension of the dichotomous Rasch model suitable for use when items have polytomous categories (Masters, 1982), using response data from a survey of teachers. They observed a high mean response rate and small number of responses in the lower Likert scale categories, suggesting that the original seven Likert response categories could be reduced. A Rasch analysis in which the original seven Likert categories were recoded into four categories provided strong evidence for four substantive categories, which allowed for valid and substantial differences to be discerned between the categories (Saubern et al, 2019).

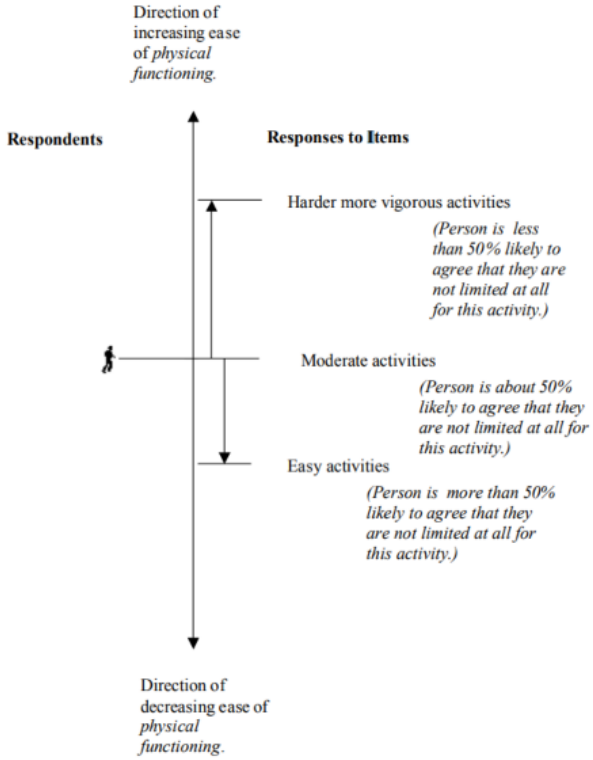
Several studies using Rasch modeling on data from TPACK instruments have produced person-item maps (or Wright Maps) that show the distribution of difficulties of the items and the ability of the sample population against the measurement scale. Drawing on evidence from person-item maps, Singer (2016) observed that most of the items were too easy for the participants and there were few items that were able to discriminate between participants at higher levels of ability. Fùtterer et al (2023) observed a similar mismatch between the difficulty of the items and the ability of the surveyed teachers indicated in the person-item map for their TPACK survey tool.

From Quantitative Scores to Qualitative Descriptions

In a paper focused on validating TPACK measurements, Cavanagh and Koehler (2013) noted the opportunity afforded by person-item maps constructed from Rasch modeling to profile the TPACK development of teachers. Wilson (2003) describes how the probabilistic relationship between a person's ability on a Rasch measurement scale and an item's difficulty can be used to provide qualitative descriptions of a person's ability at a given point on the scale. He gives an example of a respondent to a questionnaire on ease of physical functioning (figure 2). Respondents at the same location on the scale as an item tend to respond positively to that item about 50% of the time, more often to those items below their ability and less often to those above. Because of this relationship between a person's ability and the difficulty of an item, a person's proficiency can be described qualitatively in terms of their ability to respond correctly to those items above, at, or below their level (Nakano & Primi, 2014).

Figure 2

Construct Map Illustrating the Interpretation of Different Item Locations with Respect to a Single Person.[2]

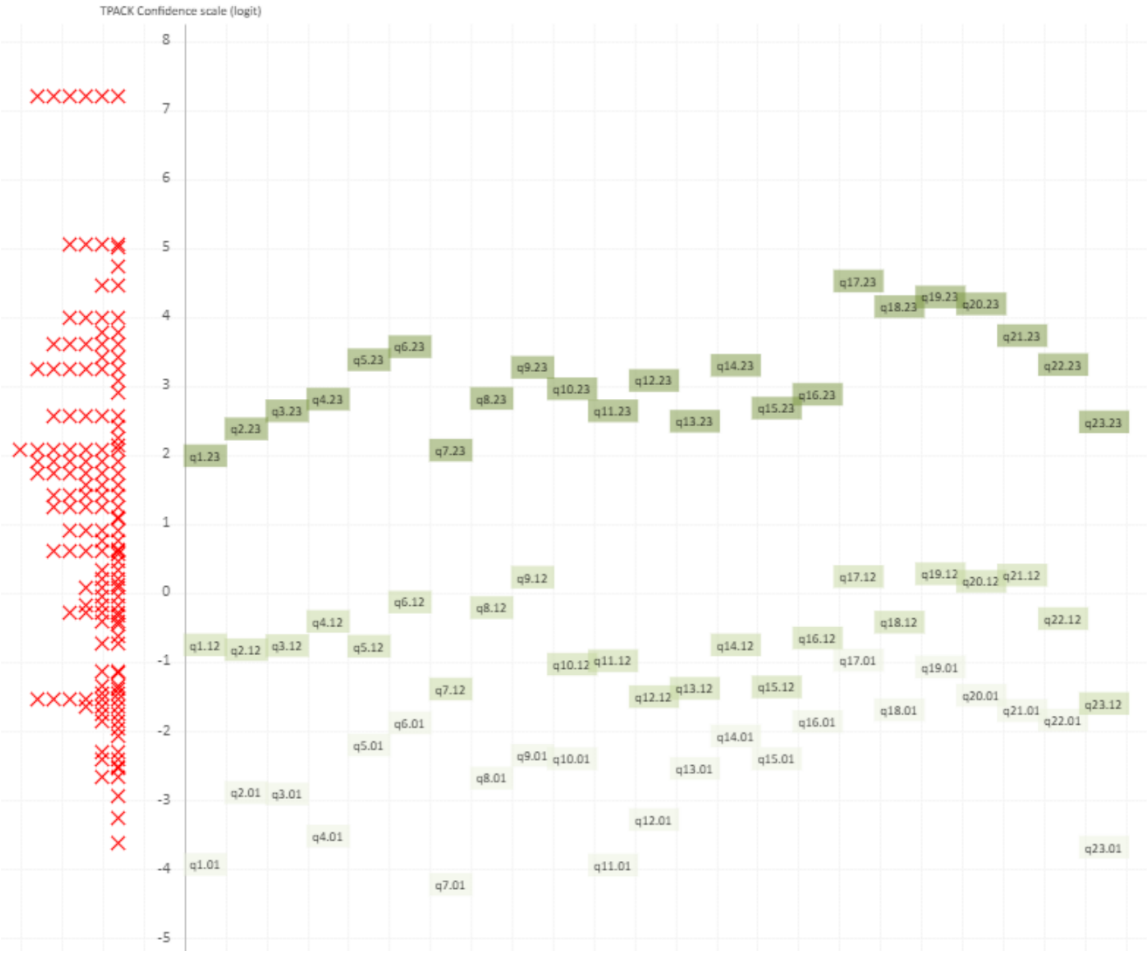


Saubern et al. (2019, 2020) reported a person-item map for the TPACK Confidence construct produced from a partial-credit analysis of data from a TPACK survey tool (figure 3). Rather than the mean difficulty of the item, this map shows the item parameters as item category boundaries for the response categories for each item. The range on the scale between item parameters q1.01 and q1.12 shows the range on the scale at which it is more likely that a person agrees that they are "moderately confident" in their response to question 1 than "less confident"; the range on the scale between item parameters q1.12 and q1.23 is the range on the scale that a person is more likely to agree that they are "very confident" in response to question 1 than "moderately confident"; and the range on the scale above item parameter q1.23 is the range on the scale that a person is more likely to agree that they are "extremely confident" in response to question 1 than "very confident" (Saubern et al, 2020).

[2] Reproduced from Wilson (2003) Figure 1.

Figure 3

TPACK Confidence Person-Item Map. Reproduced from Saubern et al (2020).



The person-item map shows that a teacher with a scale score of 1.0 logits is less likely to respond to item 1 as "extremely confident" (category 3), which is above her ability to confidently agree with these survey statements, and more likely to respond to item 1 as "very confident" (category 2), which is at her ability (to confidently agree with these survey statements). By contrast, a teacher with a scale score of -2.0 logits is less likely to respond to item 1 as "very confident" (category 2) and more likely to respond to item 1 as "moderately confident" (category 1). Such differences can be used to differentiate the ability of the teachers, providing a qualitative description of their quantitative measurement scores. The first teacher, with a scale score of 1.0 logits, can be described as likely to be "very confident" that she has "the knowledge, skills and attributes to support students' use of ICT to provide motivation for curriculum tasks" (Saubern et al, 2020, p. 9). The second teacher, with a scale score of -2.0 logits, can be described as likely being "moderately confident" he has "the knowledge, skills and attributes to support students' use of ICT to provide motivation for curriculum tasks" (Saubern et al, 2020, p. 9).

Using observations of the hierarchical difficulties of the item category boundary parameters, it is possible to construct a qualitative description of the scale in the form of a construct map (Nakano & Primi, 2014; Wilson, 2003). In Saubern et al (2020), hierarchical difficulties of the item category boundary parameters of eight of the items shown in the person item map were used to produce a construct map for aspects of the scale TPACK Confidence, with five qualitatively

described bands each of the two logits length, from -4.0 logits to 6.0 logits (figure 4). The band descriptors describe the TPACK Confidence ability of teachers with a scale score in that band in terms of their typical confidence in their skills, knowledge, and attributes to use technology. While the focus in Saubern et al (2020) was on describing the TPACK Confidence construct, the probabilistic relationship between the teachers' ability scores and the difficulty of the items means that the construct map can also be used to describe the ability of individual teachers using their survey responses.

Figure 4

TPACK Confidence Construct Map. Reproduced from Saubern et al. (2020)

TPACK Confidence	Band	Description
↑	Teachers in **Band 5** are typically… 12% of respondents	… **extremely confident** that they have the knowledge, skills and abilities to support students' use of ICT to actively construct knowledge that integrates curriculum areas, actively construct their own knowledge in collaboration with their peers and others, analyze their knowledge, synthesize their knowledge, develop deep understanding about a topic of interest relevant to the curriculum area/s being studied, plan and/or manage curriculum projects, engage in sustained involvement with curriculum activities and facilitate the integration of curriculum areas to construct multidisciplinary knowledge.
	Teachers in **Band 4** are typically… 21% of respondents	… **beginning to be extremely confident** that they have the knowledge, skills and abilities to support students' use of ICT to actively construct knowledge that integrates curriculum areas, actively construct their own knowledge in collaboration with their peers and others, develop deep understanding about a topic of interest relevant to the curriculum area/s being studied and plan and/or manage curriculum projects and **very confident** that they have the knowledge, skills and abilities to support students' use of ICT to analyze their knowledge, synthesize their knowledge, engage in sustained involvement with curriculum activities and facilitate the integration of curriculum areas to construct multidisciplinary knowledge.
	Teachers in **Band 3** are typically… 32% of respondents	… **very confident** that they have the knowledge, skills and abilities to support students' use of ICT to actively construct knowledge that integrates curriculum areas, actively construct their own knowledge in collaboration with their peers and others, analyze their knowledge, synthesize their knowledge, develop deep understanding about a topic of interest relevant to the curriculum area/s being studied, plan and/or manage curriculum projects, engage in sustained involvement with curriculum activities and facilitate the integration of curriculum areas to construct multidisciplinary knowledge.
	Teachers in **Band 2** are typically… 25% of respondents	… **beginning to be very confident** that they have the knowledge, skills and abilities support students' use of ICT to develop deep understanding about a topic of interest relevant to the curriculum area/s being studied and plan and/or manage curriculum projects and **moderately confident** that they have the knowledge, skills and abilities to support students' use of ICT to actively construct knowledge that integrates curriculum areas, actively construct their own knowledge in collaboration with their peers and others, analyze their knowledge, synthesize their knowledge, engage in sustained involvement with curriculum activities and facilitate the integration of curriculum areas to construct multidisciplinary knowledge.
	Teachers in **Band 1** are typically… 10% of respondents	… **moderately confident** that they have the knowledge, skills and abilities to support students' use of ICT to actively construct their own knowledge in collaboration with their peers and others, **beginning to be moderately confident** that they have the knowledge, skills and abilities to support students' use of ICT to actively construct knowledge that integrates curriculum areas and **less confident** they have the knowledge, skills and abilities to support students' use of ICT to analyze their knowledge, synthesize their knowledge, develop deep understanding about a topic of interest relevant to the curriculum area/s being studied, plan and/or manage curriculum projects, engage in sustained involvement with curriculum activities and facilitate the integration of curriculum areas to construct multidisciplinary knowledge.

To find the ability of an individual teacher and therefore their location on the scale and construct map, it is necessary to derive a scale score corresponding to each raw score from the survey, as raw scores alone are not suitable for use on Rasch measurement scales (Cavanagh & Koehler, 2013). In the case of the Rasch scale reported in Saubern et al (2020), the location of each teacher can be calculated using a two-step process. First, the teacher's survey responses are converted from the original seven-category Likert scale to the four categories substantiated by the Rasch analysis (table 1) and the transformed responses summed to produce a raw score. Second, the teacher's raw score is converted to a scale score (table 2), reported in logits. Using this scale score, any teacher who has completed the survey tool used in Saubern et al. (2020) can be located on the scale and their TPACK ability described qualitatively in terms of the band descriptors in the construct map.

Table 1

Transformed Raw Score Matrix

Original Likert category	Transformed 4-category raw score
0-Not confident	0-Less confident
1	
2	
3-Moderately confident	1-Moderately confident
4	2-Very confident
5	
6-Extremely confident	3-Extremely confident

Table 2

Score Equivalence Table

Transformed raw score	Ability estimate (logit)	SE (logit)	Transformed raw score	Ability estimate (logit)	SE (logit)	Transformed raw score	Ability estimate (logit)	SE (logit)
0	-6.774	1.484	**24**	-1.415	0.320	**48**	1.602	0.408
1	-5.603	0.881	**25**	-1.314	0.320	**49**	1.770	0.408
2	-5.021	0.700	**26**	-1.213	0.320	**50**	1.938	0.408
3	-4.614	0.606	**27**	-1.112	0.320	**51**	2.105	0.408
4	-4.293	0.546	**28**	-1.011	0.321	**52**	2.271	0.407
5	-4.025	0.504	**29**	-0.909	0.322	**53**	2.436	0.407
6	-3.791	0.472	**30**	-0.806	0.324	**54**	2.600	0.407
7	-3.584	0.447	**31**	-0.702	0.326	**55**	2.764	0.409
8	-3.396	0.427	**32**	-0.596	0.329	**56**	2.929	0.411
9	-3.223	0.410	**33**	-0.488	0.332	**57**	3.096	0.415
10	-3.063	0.396	**34**	-0.377	0.336	**58**	3.266	0.420
11	-2.913	0.384	**35**	-0.264	0.340	**59**	3.441	0.427
12	-2.772	0.373	**36**	-0.148	0.344	**60**	3.623	0.437
13	-2.638	0.364	**37**	-0.029	0.350	**61**	3.813	0.449
14	-2.510	0.356	**38**	0.095	0.355	**62**	4.016	0.465
15	-2.387	0.349	**39**	0.223	0.361	**63**	4.235	0.486
16	-2.268	0.344	**40**	0.356	0.368	**64**	4.476	0.514
17	-2.154	0.338	**41**	0.495	0.374	**65**	4.749	0.553
18	-2.042	0.334	**42**	0.638	0.381	**66**	5.072	0.610
19	-1.934	0.330	**43**	0.788	0.388	**67**	5.479	0.702
20	-1.827	0.327	**44**	0.943	0.394	**68**	6.059	0.881
21	-1.722	0.325	**45**	1.103	0.399	**69**	7.226	1.482
22	-1.619	0.323	**46**	1.267	0.403			
23	-1.517	0.321	**47**	1.434	0.406			

Identifying the Location of a Teacher on the TPACK Confidence Scale

DE is a year 11 and 12 English teacher at a large, K-12 school. She participated in a case study conducted in 2021 as part of a larger study focused on teacher understanding of effective use of technology in the classroom. DE has 10 years of teaching experience at her current school. As part of the evidence gathering for the case study, DE was asked to complete a modified version of the TTF TPACK Survey tool (Jamieson-Proctor et al., 2013; Saubern et al., 2020). DE's responses to the TPACK Confidence survey items are shown in table 3 and ranged from 0-6 on the 7-category Likert scale. Using the recoding matrix (table 1), the responses are transformed into 4-category responses (0-3). The summed total of DE's transformed raw score is 34. The score equivalence table (table 2) shows a raw score of 34 equates to a scale score of -0.377 logits, with a standard error of 0.336 logits. A scale score of -0.377 logits locates DE in Band 2 on the TPACK Confidence scale, that is between -2.0 logits and 0.0 logits (Saubern et al, 2020).

Table 3

DE's Responses to the TTF TPACK Survey

Item #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
7-category response	4	5	5	3	3	4	3	3	3	3	4	4	4	4	3	3	4	4	3	3	4	3	3
4-category response	2	2	2	1	1	2	1	1	1	1	2	2	2	2	1	1	2	2	1	1	2	1	1

DE's location on the TPACK Confidence scale can be described probabilistically in terms of the item parameters with which she is most likely to agree. Looking at the person-item map (figure 3), her location at -0.377 logits corresponds with many of the items just above the .12 parameter boundaries but well below the .23 boundaries, suggesting that for these items, her most likely response is "very confident". On the other hand, there are some more difficult items (for example, items 9 and 17) for which -0.377 logits is below the .12 parameter boundaries but above the .01 parameter boundaries, which suggests her response is most likely to be "moderately confident". This is summarized for eight items in the descriptor of Band 2 in the TPACK Construct Map (figure 4):

> … **beginning to be very confident** that they have the knowledge, skills and abilities support students' use of ICT to develop deep understanding about a topic of interest relevant to the curriculum area/s being studied and plan and/or manage curriculum projects and **moderately confident** that they have the knowledge, skills and abilities to support students' use of ICT to actively construct knowledge that integrates curriculum areas, actively construct their own knowledge in collaboration with their peers and others, analyze their knowledge, synthesize their knowledge, engage in sustained involvement with curriculum activities and facilitate the integration of curriculum areas to construct multidisciplinary knowledge. (Saubern et al., 2020, p. 9)

Comparing this to the description of the next highest band, highlights the qualitative differences between the knowledge, skills, and attributes of teachers at Band 2 and Band 3. Teachers at Band 3 are typically more confident than teachers in Band 2 in integrating technology to support students to collaborate, analyze, and synthesize across curriculum areas, but have similar level of

confidence in supporting students to develop understanding of a topic and planning a curriculum project. For DE to reach Band 3, she would need to develop the skills, knowledge, and attributes in specific areas that would give her confidence to report a higher level of proficiency.

Discussion

While measuring teachers' TPACK and TPACK development has been a central purpose of TPACK research, there are limitations in interpreting quantitative scores derived from tools based on CTT approaches (Cavanagh & Koehler, 2013; Singer, 2016; Wilson, 2018). Survey tools using Likert scales or scored rubrics using simple scoring models to measure growth and development in TPACK provide some sense in which respondents are developing the extent of their proficiency. For example, Deng et al (2017) observe that teacher education students' mean TPACK score of 3.77 out of four "suggested that the participants in some degree were able to design ICT-integrated lessons, but their lesson design capacity and pedagogical reasoning can be further improved" (Deng et al., 2017, p. 11). Lachner et al. (2021) observe that an increase in scores from 3.40 to 3.82 in the intervention group showed that "the intervention condition demonstrated higher levels of self-efficacy than the control condition" (Lachner et al., 2021, p. 11). These and similar observations frame development in terms of increasing raw scores. Generally speaking, however, other than inferring that a higher score is higher than a lower score, the arbitrary nature of raw scores does not provide a strong basis for interpreting the meaning of differences between score points (Cavanagh & Koehler, 2013; Singer, 2016). Related to this, while many studies report separately on scores for different measures or different components of a single measure, without a scaling model (Cavanagh & Koehler, 2013), it difficult to interpret the meaning the relationships between the scoring models for each item and the scoring model for each item and the construct as a whole (Carney et al., 2023; Cavanagh & Koehler, 2013). For example, Akyuz (2018) compares the scores of teachers on aspects of Schmidt et al's (2009) survey tool, noting "a higher level of content (4.0) and pedagogical (4.2) knowledge than technological knowledge (3.6)" (Akyuz, 2018, p. 221), suggesting that the Likert categories for each subscale are in some way comparable, that is, the meaning of 4 in one is broadly indicative of the same level of proficiency as a 4 in another.

IRT has several advantages over CTT approaches and can be seen to be a development or improvement on those approaches, including in relation to describing latent constructs, validating measurement tools, and generating interval measurement scales that can be used to compare fairly across persons and times (Bovaird & Embretson, 2008). A useful feature of IRT is the ability to make direct (probabilistic) comparisons between a person's ability and an item's difficulty, allowing for a qualitative interpretation of a person's ability score (Bovaird & Embretson, 2008; Nakano & Primi, 2014). Such qualitative interpretations of quantitative results have potential benefits both in teacher education contexts and in research. Teacher educators using TPACK measurement instruments with qualitatively described scales can generate useful diagnostic information about student strengths and weaknesses and qualitatively interpret measured improvements in TPACK in terms of the curriculum and pedagogical goals of the program. Researchers measuring teachers' TPACK in research settings can better understand the relationship between teachers' TPACK and current performance, and infer relationships between intervention characteristics and the skills, knowledge, and attributes of teachers and any measured changes.

For example, having identified a range of developmental needs for DE, a teacher educator could design an in-service development program focused on development in key areas. Following the completion of the program, DE could be asked to complete the survey again. Any measured increases in DE's TPACK confidence could then be reviewed against the goals of the teacher education program and DE's ongoing development needs re-evaluated. Further, a researcher investigating the conditions for successful integration of technology in classroom settings could

note not just that students in DE's classes had more positive outcomes following her in-service development but make direct connections between the knowledge developed and the success conditions for the technology integration.

Conclusion

IRT has been used in TPACK related research mainly to establish the validity of measurement tools and provide feedback on improvements to those tools (Bakar et al., 2019; Fütterer et al., 2023; Jamieson-Proctor et al., 2013; Pieters, 2019; Puspitasari et al., 2020; Singer, 2016). A feature of IRT, which has been underutilized in TPACK research, is the ability to qualitatively describe quantitative measurement scores, using the probabilistic relationship between a person's ability score and the difficulty of an item or item parameter. In this paper, the location of a teacher who had completed the TTF TPACK Survey on the TPACK Confidence scale was identified by converting their raw score responses on the survey to a scale score, providing a qualitative description of that teacher's TPACK derived from eight items in the survey. Such a qualitative description provides useful diagnostic information about a teacher's current TPACK and developmental needs. A repeat measurement following DE's involvement in a teacher education in-service would provide useful data on any increases in TPACK that are directly relatable to the curriculum and pedagogical goals of the teacher education program.

Limitations and Recommendations

The conclusions of this paper are limited by the small number of cases examined but lead to potentially useful propositions on extending the use of IRT in TPACK related research. Future studies focused on producing richly described, qualitative interpretations of quantitative measurement scores generated using IRT could further explore the opportunities to qualitatively interpret TPACK change and development in context. The development of such rich descriptions could also generate useful evidence for the relationship between teachers' developing TPACK and other related skills, attributes and outcomes.

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EXPLORING THE GAP: TEACHER IDENTITIES IN INITIAL TEACHER EDUCATION AND CLASSROOM REALITIES

Ottavia Trevisan
University of Padova, Italy
ottavia.trevisan@unipd.it,

Abstract. Initial teacher education (ITE) programmes equip pre-service teachers with strong professional knowledge, attitudes, and skills. Moreover, they foster competencies to teach in the Digital Era. However, a worrying number of newly qualified teachers experience a reality shock when they enter the profession, experiencing tensions, burnout symptoms, and less-than-optimal teaching performance. Internships during ITE may be the key to bridging the gap between theoretical education and classroom practice, but do they really help? This study conducted during the 2021-2022 academic year explored the internship experiences of 38 pre-service teachers. Through interviews, this study explores the ideals and characteristics of teacher identities perceived by pre-service teachers in the ITE and internship contexts, with a focus on the role of technology in education. Findings highlight an expectation gap along with a vulnerability to succumb to contextual pressures, even safe environments of the internship. The recommendations from this study include closer collaboration between ITE programs and internship settings to sustain teachers' organic identity and future agency.

Keywords. Initial Teacher Education, Teacher Identity, Internship, Reality Shock

Introduction

Initial teacher education (ITE) programs are designed to equip aspiring educators with a solid foundation of professional knowledge, attitudes, and skills – which shape a high-quality teacher identity (Beauchamp & Thomas, 2011). However, new teachers often encounter a discrepancy between their conceptualizations of teaching and the actual demands of their teaching environments, particularly amidst the increasing integration of technology (Voss & Kunter, 2020). This misalignment between the professional identity cultivated during their ITE program and the complex, technology-driven realities they face in the classroom may lead to a phenomenon known as reality shock (Sheffield et al., 2020). Despite internships during ITE intended to bridge the gap between theory and practice, their effectiveness in doing so remains uncertain.

This paper seeks to contribute to the ongoing discourse on the development of teacher identity from the very start of ITEs, to empower future educators to face complex expectations and evolving realities in today's technology-rich classroom. The research underpinned explores the perceived mismatches between teacher identities (a) envisioned by pre-service teachers, (b) experienced during ITE, and (c) those expected by school contexts (i.e., internships). The research also delves into the professional tensions identified by pre-service teachers as potential early signs of reality shock upon entering the profession (Harrison et al., 2023). This study's ultimate goal is to contribute insights to the customization of ITE programs to better prepare future professionals for the complex and technology-rich realities of the modern classroom, and its research questions are:

1. How do pre-service teachers perceive teacher identities as proposed by their ITE program, emerging from internship school contexts, and individually nurtured?
2. How do pre-service teachers perceive the role of technology integration within their definition of teacher identity?
3. How do pre-service teachers perceive emerging professional tensions in their internship contexts?

In response to these questions, a review of literature followed by the conceptual framework are presented. Next, the methodology used to collect and analyze data related to the research is described followed by a discussion of the results.

Literature Background

Teacher Identity and Professional Tensions

Defining teacher identity is a matter of ongoing debate, although it is widely agreed that it is dynamic and ever evolving, shaped by socio-cultural contexts, and characterized by educators' agency in responding to challenges and opportunities (Akkerman & Meijer, 2011; Hanna et al., 2022). This construct encompasses multiple dimensions such as motivation, commitment, values, attitudes, roles, and experiences, and it is influenced by personal and professional identities intertwined over time (Canrinus et al., 2012; Hanna et al., 2019; Rinne et al., 2023; Rosdi et al., 2020).

In today's volatile and complex educational landscape, nurturing pre-service teachers' professional identity is crucial. A robust professional identity empowers novice teachers, aiding to their resilience and adaptability while confronting challenges and reality shock (Rinne et al., 2023; Sheffield et al., 2020). Conversely, a lack of professional identity can lead to stress and burnout, contributing to attrition (Harrison et al., 2023; Sheffield et al., 2020; Skaalvik & Skaalvik, 2018). Moreover, teacher well-being (or lack thereof) and instructional quality are closely tied to students'

learning outcomes (Hadar et al., 2020; Harrison et al., 2023). Therefore, working to enhance pre-service teachers' professional identity can foster retention, elevate instructional quality, and ultimately improve students' learning experiences.

Professional identity plays a significant role in novice teachers' ability to navigate challenges, such as reality shock, which arises from conflicts between theoretical understandings and real-world experiences encountered during fieldwork (Blömeke et al., 2015; Gardesten & Herrlin, 2024; Pillen et al., 2013; Rodrigues & Mogarro, 2019). These tensions, including conflicts between personal and professional roles and differences between expectations in university training and internships, can lead to emotional exhaustion and burnout, and ultimately attrition if neglected (Anspal et al., 2019; Harrison et al., 2023; van der Wal et al., 2019; Voss & Kunter, 2020).

Professional identity development is particularly crucial in the context of technology integration, as teachers are evermore called to navigate the complexities of technology-rich classrooms (Lai & Jin, 2021). Teacher professional identity is malleable and evolves through experience (Hanna et al., 2022; Li et al., 2022; Rinne et al., 2023), particularly in the context of technology integration (Lai & Jin, 2021). For novice teachers aiming to achieve full professional status, identity development is both a catalyst and a consequence of their survival (Valtierra, 2016). Professional tensions significantly influence new teachers' sense of identity (Li et al., 2022). As such, understanding how ITE contributes to the development of professional identity is imperative for supporting educators' careers and well-being (Valtierra, 2016). By addressing professional tensions and providing support during the transition into teaching, ITE programs can play a crucial role in fostering resilient and effective educators (Li et al., 2022). Ultimately, enhancing pre-service teachers' professional identity can lead to improved retention, instructional quality, and student learning outcomes (Hadar et al., 2020; Harrison et al., 2023).

Initial Teacher Education Role for Effective Professionals

ITE programs play a crucial role in preparing future educators for the challenges they will face in the profession, offering practical experiences and reflective tasks within authentic teaching environments (Botha & Rens, 2018; Loughran, 2019). These programs aim to provide pre-service teachers with a realistic understanding of teaching, also regarding technology integration, especially through experiences like design tasks and internships (Loughran, 2019; Tondeur et al., 2020). School-based internships have been proven instrumental in exposing pre-service teachers to the complexities of school practices and nurturing their teacher identity (Hanna et al., 2022; Rinne et al., 2023). Through these experiences, pre-service teachers can engage in reflection on their teaching practices and critical incidents, facilitating their professional development (Loughran, 2019).

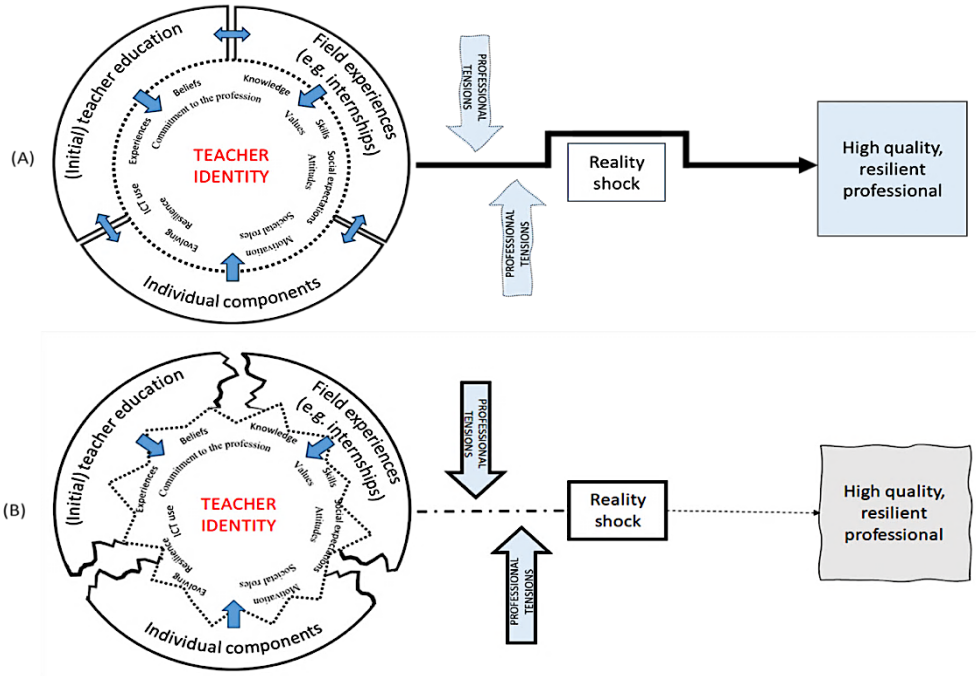
The school environment may significantly shape teachers' perceptions and experiences of the profession (Forkosh-Baruch et al., 2021; Trevisan & Smits, 2023). For example, studies suggest that the school context plays a crucial role in influencing teacher attrition and retention rates (Marlow et al., 1997; Voss & Kunter, 2020). Teachers who feel supported and integrated into their professional communities are more likely to find satisfaction and maintain commitment to their profession, thus enhancing their initial professional identity and motivation (Sheffield et al., 2020; Skaalvik & Skaalvik, 2018; Voss & Kunter, 2020). Given the profound impact of the school environment on teachers' experiences and career trajectories, internships serve as a crucial first step in exposing pre-service teachers to these realities, allowing them to begin forming their professional identities and developing strategies to navigate the complexities of the educational landscape (Rinne et al., 2023; Trevisan & Smits, 2023).

Conceptual Framework

This study's focus is on teacher professional identity as a dynamic and evolving construct, shaped by socio-cultural contexts and influenced by personal and professional experiences (Hanna et al., 2019; Rinne et al., 2023; Rosdi et al., 2020), with a slant towards technology. This focus encompasses their perceptions, motivations, dispositions towards technology integration and actual technology integrated practices (Lai & Jin, 2021). Teacher identity is influenced at various degrees by socio-cultural contexts, experiences, and professional tensions (Li et al., 2022). Teacher identity impacts attrition, retention and instructional quality of educators in the workplace (Skaalvik & Skaalvik, 2018; Voss & Kunter, 2020). Considering the abovementioned literature, Figure 1, below, visualizes the conceptual framework guiding this study.

Figure 1

Conceptual Framework for the Study



The literature on teacher identity (e.g. among many others Akkerman & Meijer, 2011; Hanna et al., 2022; Rinne et al., 2023) agrees in identifying a strong professional identity as an evolving product of well-aligned educational, professional and personal experiences and perceptions (scenario A in Figure 1). Further, it is theorized that a solid teacher identity might help educators tackle emerging professional tensions and curb reality shock, increasing the chances for higher quality, resilient professional practices. On the contrary, whenever educational, professional and personal experiences are misaligned, the resulting teacher identity seems to be more fragile (Scenario B in Figure 1) and more susceptible to professional tensions' impact and reality shock experiences. This might lead to lower instructional quality and higher attrition in career life.

While these dynamics are theorized and clear in the literature, it is not clear why or how educational, professional and personal experiences and perceptions might or might not work together towards a solid teacher identity in ITE settings. The present study operates within such gap.

Present Study

This study adopted a case study approach (Yin, 2008), exploring in depth a delimited unit (i.e., preservice teachers' narratives of their professional identities in different contexts), striving for analytical – not statistical – generalizability (Yin, 2014). This methodological approach aims to report on the "complex dynamic and unfolding interactions of events, human relationships and other factors" (Cohen et al., 2005, p. 181). Specifically, it considers the relations between the phenomenon at stake (teacher identity) and the context (ITE, internships), uncovering possible tensions arising in the latter.

Participants

The study used a convenience sample strategy based on specific inclusion criteria:

- Participants were drawn from ITE programs at university-level institutions.
- Participants were actively involved in school-based internships with teaching duties beyond observational ones (at least 6 months in, at the time of the study).
- Participants spoke English at least at B2 level (self-affessment).

Specifically, 38 pre-service teachers in the final stages of three ITE programs (2021-2022 academic year) were recruited. Aligning with the case study approach, the selection of the ITE programs strived to ensure the highest variety of manifestation of the phenomenon while still balancing researcher's accessibility to meaningful data (Yin, 2008). Hence, among the three ITE programs, two were based in Europe (one north and one south), and one in the United States (central). The researcher first introduced the study to university staff, university-based internship supervisors, and the preservice teachers, through online meetings and emails, in the early 2021. All pre-service teachers who volunteered signed an informed consent form after reading information on the research and the protocol in their native language. Further details are provided in Table 1.

Table 1

Participants' Demographics

	ITE program 1 (South Europe – n = 16)	ITE program 2 (North Europe – n = 15)	ITE program 3 (United States – n = 7)	Total (N=38)
Gender (%)	93% F, 7% M, 0% Other	73% F, 27% M, 0% Other	86% F, 14% M, 0% Other	84% F, 16%M, 0% Other
Age (average)	22.5 ±3	21±2	23±5 (one outlier 30+)	22±5
Enrolled year in ITE	Fifth out of five	Fourth out of four	Fifth out of five	Fourth to fifth out of five
Training to be	preK-8 generalist	K-8 generalist	K-8 generalist	preK-8 generalist
Previous experience outside university	None	None	None	No previous experience teaching
Performing an internship	At a K-8 school 40h/y teaching duties	At a K-8 school Up to 60h/y teaching duties	At a K-8 school Up to 40h/y teaching duties	At a K-8 school, actively teaching

Data Collection and Analysis

The qualitative investigation employed semi-structured interviews conducted on Zoom, in one-on-one settings, lasting on average 45 minutes each. They were videorecorded upon permission by the participants.

Identity theory suggests that specific identities can be triggered specifically (Burke & Stets, 2009; Hanna et al., 2022), and research indicates that questions about teaching and the profession can activate teacher identity (Hanna et al., 2022). These insights guided the development of the interview protocol, which included questions about teacher ideal characteristics in different contexts (i.e. university, internship school, and personal) to trigger the elicitation of the interviewees' understandings of teacher identity. Moreover, questions about teaching routines observed/experienced in the internship contexts were used to explore participants' professional tensions, considered proxy of early indicators of reality shock (Harrison et al., 2023; van der Wal et al., 2019). Table 2 presents a sample of the questions used in the interview protocols (see Trevisan, 2024 for more details).

Table 2

Sample Questions from the Interview Protocol

Dimension of inquiry	Questions (examples)	Relation to RQ
Teacher identities per context	How would you describe the teacher your university wants you to be? How would you describe the teacher your internship school expects you to be? How would you describe the teacher you want to be?	RQ1
Technology role	Where (if at all) does technology integration fit in these teacher ideals?	RQ1a
Professional tensions	Can you describe me the teaching style(s) of the teachers around you, in the internship context? How do you relate to those? Do you feel free to teach the way you prefer? What is your biggest challenge?	RQ2

The interview transcripts were coded in Qualitative Data Analysis (QDA) Miner 6. The analysis aimed to identify: emerging teacher definitions from school contexts and ITE programs, mentions of technology integration concerning teacher ideals definition, and perceived context-bound characteristics serving as early indicators of reality shock.

Initially, the researcher coded transcripts based on the dimensions of teacher identity found in the literature (e.g. motivation to the profession, commitment, beliefs, knowledge, values, skills and so on – see Figure 1), and used open coding for themes related to different characteristics of teacher identity emerging from the data. A total of 91 codes were assigned to the interview data in this first phase. Consecutive axial coding (Babbie, 2020) was then employed to identify which codes from open coding were the most relevant to the research question and how they connected with each other, hence creating code categories. Further details on the coding scheme are reported in Table 3, and the whole codebook will be made available upon request.

The frequency and co-occurrence of the sub-categories for teacher identities (Table 1) were examined to address the first research question, considering their appearance in relation to specific contexts (i.e. ITE, internship, personal ideals). The frequency of technology uses' codes was considered only in their co-occurrences with the emerging codes within teacher identity category. As per research question 1, technology use's relevance in this study lies in its perceived role to shape teacher identity. This choice is based on the prioritization of the concept of technological affordances for education (Angeli & Valanides, 2018). Technology carries technical affordances that teachers notice from a pedagogical standpoint. Only at that point, and in the specific way the teacher is pedagogically employing the specific technological affordance they noticed, technology use becomes relevant in the teaching-learning process (Angeli & Valanides, 2018).

Finally, the frequency of the sub-categories for observed instructional styles and strategies in internships were used as background information to understand and contextualize professional tensions (research question 2). This last category was observed in its sub-categories and codes' frequency to go deeper into the identification of early precursors of reality shock.

Table 3

Coding Scheme Structure with Examples

Category	Sub-category and definition	Codes (examples)	Exemplary quotes (examples)
Characteristics of teacher identity	Innovative. Priority is to be on the verge of educational change, defying the status quo. Includes 21st century skills and competence-based learning. Performative. Priority is on performing according to institutional/societal expectations. No clear personal/professional reflection on the practices enacted is provided. Extremely prone to external pressure.	Anti-lecture attitude. … Lack of accountability. …	P38: that's what makes me give different lessons because [the university] always said "just look at it from another perspective" *P15: [headmasters] always advocate for kindness and making sure [pupils] understand and all of that, but I think their main goal is [for the teacher] to make the kids score well, achieve well. They're looking for teachers who help students achieve academically.*
	Expert. Priority is on the teacher to be knowledgeable on the topics / strategies / resources.	Pedagogical content knowledge. …	P7: I notice in the classrooms I go to [during internships] there are teachers who have not been trained in our [university], who lack some important theoretical bases, which make us the teachers with that extra quid.
	In control. Priority is on teaching methodologies/approaches or learning features indicating a strong control by the teacher.	Teacher possesses all knowledge.	P30: they demand autonomy both in the management of the class, and in the management of the out-of-class.
	Reflective. Priority is on the idea of a teacher who reflects along the way and asks him/herself questions on teaching efficacy for learning.	Self-regulatory.	P29: I need to set those expectations better and I need to set the rules better at start of the year so I can, you know, let up at the school year for progression. But now sometimes I'm not.... There are times when I'm more of a friend to them than I am the teacher. And, that's the balance I need to figure out, but I'm not there yet
	Relationship with pupils. Priority is to have a good relationship with their pupils: e.g. getting to know them personally, spending quality time with them, being perceived as a role model.	Growth-oriented.	*P3: someone who's really interested in her pupils, not only how they are scoring on tests or something, but also how are they really doing and what kind of people are they and what do they want.*
	Inclusive. Priority is to be a teacher capable of acknowledging and addressing diverse learning needs, modifying practice to include each child, without lowering expectations.	Personalized instruction.	P18: I want to be a teacher who's there for the children, who helps [them] get further on in their lives and gets them on a new level on their own times.
	Collaborative. Priority is on collaboration with colleagues / families / pupils / territory.	Learning from others.	P14: A teacher smart, always studying, not stable in what she knows. A dynamic teacher with a lot of ideas and collaborative with the students but also with colleagues and…always in movement teacher. I think not static like "here is the book" and I hope to be one.
	Flexible. Priority is on the capability to think on the spot, assessing the context and emerging needs, modifying practice. It does not comprise surrendering a-critically to contextual demands.	In-class instructional design modification.	P 28: you have to be flexible, so I plan certain activities and then if the children show specific interests, or want to deepen a certain thing, I tend to deepen them, but in any case, I plan.
Technology uses.	Affordances. Identified uses for technology in terms of educational goals.	Drill and practice. Compensative for special needs.	P10: I made a PowerPoint to make sure that I keep like structure. I put a Lesson goal up and made a way to check after, at the end of the lesson, how to check if they really reach the goal at the end.

		Student engagement. Fun.	P7: [the use of iPad] mainly is to practice and exercise something that they are already supposed to know
Observed instructional styles and practices in internships	Teaching strategies. Description of learning activities in terms of teacher role within them.	Differentiation. Discipline management. Technology uses.	P33: [my cooperating teacher[3]] was very quiet because the other teacher was teaching, but still she was like very subtle like speaking with her eyes and like small hand movements to keep the class from speaking and behaving [badly]. So that was really interesting for me to see like how to use your body language to keep the class from being chaotic.
	Instructional phases. Description of the phases of instruction observed as most prevalent.	Introduction/direct instruction. Build new knowledge.	P11: I think just to see and watch if the children were really making progress with the poster with their projects and to help them get on because the quality of the work wasn't really there.
Professional tensions	Contextual pressure: description of a specific contextual pressure on some issues. It implies a tension between personal intention and a strong/clear contextual influence on the participant behaviour.	Discipline management routines.	P4: I tried to do things for the for the school for my teacher, but they actually found it really hard, so I sent in like "I can do this or I can give a lesson about this or I'll make a YouTube video or something" or... But it was hard for them to kind of accept that and let me do stuff.
	Surrender to contextual pressure: reports on passive/complete acceptance of contextual pressure on an issue.	Teaching approaches and routines.	*P26: "why" [I do anything in my internship] is because my [cooperating] teacherasked me to do this, this subject, and this way.*
	Overwhelming pressure. Description of a feeling of being overwhelmed by expected behaviours, with no foreseeable individual agency. Reasons could be related to personal strategies to address the issue and/or professional (low) self-efficacy.	Teacher approach.	*P11: you learn all sorts of nice activities with technologies, to be innovative and creative. But then the reality is that schools are not equipped. There is no stable internet, not enough computers. And teachers don't know how to use them either, so.*

[3] A cooperating teacher is a mentor teacher assigned to training pre-service teachers in their internship schools.

Validity and Reliability

The data collection was carried out in English by this study's researcher, who had no connection to participants' educational courses. To ensure data reliability, a native speaker-English interpreter – not connected to the participants – was present during the interviews to provide translations when needed. To allow for open communication, participants were reassured about the anonymity of their answers, as well as the lack of any connection or consequence to their courses. Despite the potential for desirability bias in responses, the collected data, as will be discussed, indicate that participants felt free to express opinions, including unfavorable views on ITE. Further, the transcribed interview data were sent back to the interviewees for approval, and subsequently modified where requested. This paper utilizes the approved dataset and employs pseudonyms (progressive numbers) when quoting participants.

During data analysis, recursive coding was used to ensure reliability and trustworthiness (Peterson, 2019).

Findings

The findings will be presented separately for each research question, incorporating relevant codes and quotations from the interviewees. Within each section, reported percentages indicate the number of participants mentioning specific codes, as the frequency of codes across interviewees was deemed more informative than the code incidence (intensity) per person.

ITE and School-Based Teacher Ideals

The interviewees discussed their developing professional identity in three contexts: (a) the teacher identity they believed their university was trying to cultivate in them; (b) the teacher identity they perceived their internship schools expected them to embody; and (c) the teacher identity they personally nurtured. Figure 2 shows the codes' frequencies over the number of participants, comparing the perceived ideals in the three contexts, i.e. ITE, school-based internship and personally nurtured (N=38).

Figure 2

Perceived Teacher Ideals - Compared. Percentage of Participants Mentioning the Codes (N=38)

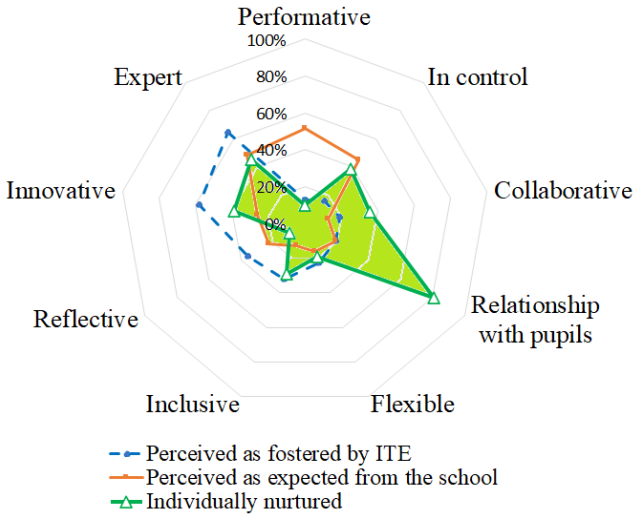


Figure 2 shows that the majority of the participants (64.5%) perceived their ITE as trying to shape a teacher identity that is characterized by *expertise* in both disciplinary and pedagogical theories, and *innovation* (58.1%). According to 35.5% of the interviewees, there is also the intent to shape *reflective* teachers who would question themselves and their own practice to be most effective. Less frequent are codes about being focused on *inclusion* (32.3%), or *flexible* (22.6%). When characterizing the teacher identity emerging from their ITE program, participants would also mention uses of technology – specifically in relation to being expert and innovative teachers, for example:

> ***P35:*** *[they want] a teacher who is very focused on, for example, using different methods and techniques and technologies. Someone who can deal with their difficulties outside the classroom, but who can be - in the classroom - what the students really need.*
>
> ***P23:*** *[according to my university, a good teacher] wants to constantly improve. Has initiative. Uses technologies to go beyond what's been done so far. So, I would say it is like you see something, and you want to solve it: no one has to tell you to go and do that, [i.e.] be a better teacher. You want to do it to become better for your students.*

On the other hand, the ideal of teacher most widely reported as expected in the internship schools was one focused on *performance* (51.6% - Figure 2). Almost half of the future teachers perceived schools as expecting them to be *expert* teachers (45.8%) *in control* of the classroom (45.2%), mainly on a discipline management point of view. Notably, no mention of technology integration was made in relation to the school-expected teacher ideals. Some relevant quotes characterizing perceived school-based teacher identity are:

> ***P7:*** *I also had some internships that didn't want to know about research [on] learning because it didn't fit in their vision of the school, so that's kind of a thing*
>
> ***P29:*** *I saw teachers that just reproduce a model that they interiorized before and it's always the same over and over.*
>
> ***P15:*** *You start your [internship] and you have to fit in this box. And if you fit in this box you are a primary teacher.*

Finally, the kind of teacher pre-service teachers themselves aspired to be was explored. As per Figure 2, interviewees' personally nurtured teacher ideals tend to align with the ones perceived as offered by ITE in relation to being *inclusive* (29%), *innovative* (38.7%) and not-*performative* (9.7%). However, the reported personal ideals agree with the school-expected ones in terms of being disciplinary/pedagogical somewhat *experts* (45.2%) and not often *reflective* practitioners (9.7%). Finally, several pre-service teachers declared they wish to be professionals that neither their ITE programs nor their school-based internships are seeking: *collaborative* (35.5%) with pupils' families and school colleagues; and most of all focused on *relationships with the pupils* (80.7%). Participants' personal definition of teacher identities also often included technology integration:

> ***P30:*** *I want to be a teacher that engages all the children and for this reason I think that I want to use various methodologies, various activities, various technologies, to connect, to engage all the children in their different needs.*
>
> ***P2:*** *[I want to be] a reflective, collaborative and inclusive teacher. I would say, someone attentive to technology and therefore more focused on competencies [than notions]. Someone who knows how to decide on objectives, formulate them, [realize them through] authentic and inclusive tasks, also using technology to cooperate both with the group of children and with colleagues and the community.*

Perceived Emerging Professional Tensions

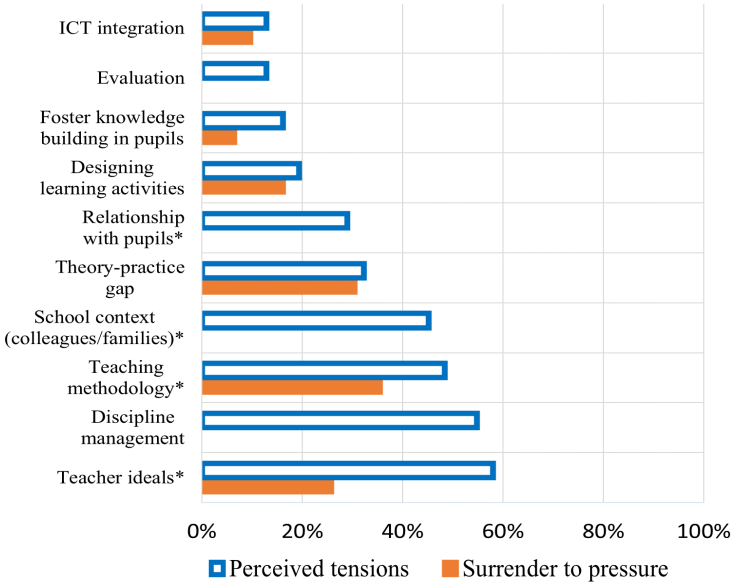
In part of their interview, participants were asked to describe a usual lesson such as observed in their internship context. Among the most common teaching and learning events described, participants reported a high frequency of textbook-based lessons based on *drill* practices (67.2%), *teacher-centered performative instruction* (83.5%), and some openness to pupils' *active participation* in defining the learning activities (72.4%). Moreover, several reported events of *discipline management* (67.6%) and the use of *technologies* to support the lesson (69.8% - e.g., P8: *The use of technology would be to exercise on this platform thing*).

Participants were hence asked how they related to contextual teaching styles/practices and if they perceived any pressure to act in a specific way. Figure 3 reports on the most perceived tensions (i.e. pressures) among the participants, and their intention to surrender to the contextual expectations even when in disagreement.

Figure 3 shows how 58.1% of the pre-service teachers perceived tensions (empty bars) related to the *ideals of teacher* expected by the school (see Figure 2), followed by discomfort in *discipline management* (54.9%), the expected teaching *methodology* (48.4%), *relationships* with colleagues and pupils' families (29%). Moreover, the pressure resulting from these tensions were often perceived *overwhelming* at the time. Part of these findings could be traced to the intrinsic power-dynamics within the internship, where a pre-service teacher is supervised closely by the internship coach and is naturally subject to them. However, since the observed teaching methodologies are highly transmissive, and the contextual teacher ideal is primarily performative, high rates of compliance (i.e. frequency of *surrender to pressure* codes) would be reason for concern.

Figure 3

Perceived Tensions and Reactions. Percentage of Participants Mentioning the Codes (N=38)



** Interviewees mentioned the pressure on this area to be overwhelming.*

Exemplary quotes on professional tensions, where contextual pressure might crash against individual's intent, are:

> ***P5:*** *[in my internship] I wanted to prepare a video to introduce the topic, but I don't want to do too much with technologies because then maybe, you know, parents may say 'look: the new teacher does that and your [usual] teachers don't do that'. Then my [cooperating teacher] would complain to me, so I follow what my [cooperating] teacher says to prepare. Hence, I made a PDF and just forwarded the materials.*
>
> ***P34:*** *I usually check the textbook beforehand, and see what exercises they have planned for the students.*

Zooming into compliance rates, Figure 3 shows how many interviewees would *surrender* to contextual expectations despite their own intentions. The most often reported area relates to the perceived *gap between theory and practice:* whenever a tension arises between theory-based expertise (likely developed in ITE) and school-based practice, the latter is the one held true and to be replicated. High ratio of surrender-to-tension is also in *technology* integration and the definition of *learning activities.* For example, there are infrastructural barriers that teachers feel hopeless against. Other times, barriers arise to the realization of personal ideals of teaching – and participants reported compliance about them. Exemplary quotes are:

> ***P16:*** *Sometimes we have [cooperating] teachers who are a bit old, let's say, and in my experience, for example with Covid the last year my colleagues didn't use technology, computers, and this is a very big problem because… some of them didn't even try.*

P1: *[my cooperating teacher] uses the JamBoard to display lesson materials - only that. And she told me [that] before the pandemic she never used any technology, so she was very happy, proud! because of her competency with the JamBoard. We are where we are.*

P36: *I didn't really like the curriculum that we used [at my internship] school for reading, writing and phonics. It was a model that I just didn't think worked very well for the students. I think we could have done it in a different, a better way, had we not been tied down to that curriculum. Now, granted: I didn't have a choice, so it didn't really matter what I thought.*

Discussion and Conclusions

The research focused on pre-service teachers' perceptions of teacher identities as shaped by ITE, expected by internship-school contexts, and personally nurtured. Additionally, it examined the role of technology in defining teacher ideals and perceptions of contextual tensions. Findings revealed a perceived disparity between the types of teachers emphasized in university and school settings, echoing previous studies (Hanna et al., 2022; Rinne et al., 2023). While ITE programs are seen to prioritize innovation, expertise, and inclusion, schools are perceived to emphasize meeting curriculum and discipline-management requirements, reiterating a dichotomy between research-driven academia and policy-influenced school systems (Pettersson, 2018). Participating pre-service teachers strive to reconcile these differing expectations by aligning with the expertise cultivated in ITE settings while striving to meet the practical demands of school environments (e.g. being performative). Moreover, individual aspirations for teacher identity often extended beyond the confines of either ITE/school context, possibly reflecting personal experiences as students (Rinne et al., 2023). Pre-service teachers in this study highly valued educational relationships with students, and collaboration with colleagues and the wider community – two characteristics not much attributed as relevant in either ITE/school setting.

Participants mentioned technology integration mostly in relation to ITE-based teacher ideals, concurring to its characterization of innovation and teacher expertise. They also traced technology integration in the characterization of their personally nurtured teacher identity, which prioritizes collaboration and meaningful educational relationships. Conversely, relevant technology mentions were missing when participants talked about teacher identities as expected by the school context. The technology use mentioned in relation to specific teacher ideals suggests that ITE programs may be successfully uncovering the importance of technology in modern teaching practices. However, the apparent absence of technology characterization in school-based teacher identity expectations highlights a potential gap between teacher preparation and actual school environments, which could lead to challenges for new teachers as they transition into their careers. This disconnect presents an opportunity for education stakeholders to bridge the gap between theoretical ideals and practical realities. Further, acknowledging and addressing pre-service teachers' views on technology in relation to the development of their professional identity could boost the efficacy of ITE strategies, helping to create more resilient and flexible new teachers.

The study also explored perceived professional tensions as early indicators of reality shock. Many pre-service teachers experienced tensions related to teacher ideals, teaching

methods, and discipline management, reflecting challenging areas in identity development described in the literature (Anspal et al., 2019; Kozikoglu & Senemoglu, 2021). For example, Anspal and colleagues (2019) talk about similar tensions related to the personal/professional roles, the conceptions of teacher at university and in the classroom, and multiple expectations. These tensions can contribute to emotional exhaustion and burnout (Harrison et al., 2023; Voss & Kunter, 2020).

Most worrying is the fact that these pre-service teachers appear highly vulnerable to surrender to contextual pressures for teaching approaches, technology use and curriculum definition, already while in the protected environment of an internship. This could speak to weak teacher identities, which could lead to higher levels of discomfort and occupational stress when entering the profession, besides lower teaching quality (Hanna et al., 2022; Harrison et al., 2023; Voss & Kunter, 2020). The vulnerability of pre-service teachers to contextual pressures during internships underscores the importance of developing strong teacher identities to withstand occupational stress and maintain teaching quality.

To foster a more organic teacher identity, ITE programs must acknowledge and reconcile conflicting perspectives among pre-service teachers (Lim et al., 2019; Rinne et al., 2023). This necessitates providing systematic opportunities for pre-service teachers to interpret pedagogical dilemmas based on their beliefs and teaching identities, bridging theory and practice (Lim et al., 2019; Rinne et al., 2023). Close cooperation between ITE programs and diverse schools' stakeholders is crucial to support pre-service teachers' development of organic identities and agency within the education system (Botha & Rens, 2018). By fostering this collaboration, new teachers can better navigate reality shock and adapt to volatile, uncertain and complex conditions, becoming proactive rather than overwhelmed by circumstances (Botha & Rens, 2018; Hadar et al., 2020). Additionally, such collaboration might better sustain the growth of effective teachers who embrace lifelong learning and adapt as technologies, pedagogies and contexts change.

Limitations

The study discussed in this article acknowledges certain constraints. Given the deeply personal nature of teacher identity, it's important to recognize that the findings are applicable primarily to the individuals involved. Hence, generalizations based on these findings are to be avoided. Nevertheless, these findings are consistent with prior research and may suggest novel avenues for investigating the incongruity of teacher identities among pre-service educators. Future studies might employ diverse data collection methods and expand the participant pool to ensure broader applicability. Additionally, exploring longitudinal and interpersonal variations of this phenomenon across various educational settings could be beneficial.

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TEACHING AND LEARNING IN SOCIAL MIXED REALITY FOCUSING ON TRANSCULTURAL EDUCATION: PRE-SERVICE TEACHERS' PERSPECTIVES

Tamara Baumann
University of Wuerzburg, Germany
Tamara.baumann@uni-wuerzburg.de

Jennifer Tiede
University of Wuerzburg, Germany

Marc Erich Latoschik
University of Wuerzburg, Germany

Silke Grafe
University of Wuerzburg, Germany

Abstract. Digitalization and globalization brought significant challenges to initial teacher education. Against this background, the researchers identify targeted implications for the development and implementation of a pedagogical concept to foster pre-service teachers' media pedagogical competence. A sample of 15 pre-service teachers from two German universities participated in a teaching and learning scenario within a social mixed reality (MR) environment focusing on transcultural education. Subsequently, their perspectives were shared during focus group discussions and then qualitatively analyzed. Results indicate a wide range of experiences as well as anticipated opportunities and challenges for central teaching and learning components. Conclusions drawn from this study should be considered in future practices and research within initial teacher education.

Keywords. Mixed Reality, Teacher Education, Transcultural Education, Media Pedagogy, Digital Competence

Introduction

The process of digitalization, alongside transcultural dynamics significantly influence the social developments of the 21st century (Jurkova & Guo, 2018; Tulodziecki et al., 2021). Consequently, schools and initial teacher education programs face new demands (Hobbs, 2017). In accordance, media education competence is paramount for the professionalization of prospective teachers (Tulodziecki, 2012). However, there is a shortfall in the competencies of this target group (UNESCO, 2023). Hence, to equip pre-service teachers with media-related competencies (Tulodziecki, 2012), it is essential to establish pedagogical concepts designed to foster them.

Digitalization refers to "the increasing importance of digital media" (Tulodziecki, 2012, p. 271), which brings about an increased use of digital media in educational processes. In this context, media technologies from the extended reality (XR) spectrum (Milgram & Kishino, 1994) have gained significance within pedagogical concepts in higher education, particularly when used in social settings (Scavarelli et al., 2021). These settings take place in pre-designed platforms that can be accessed as virtual avatars by using immersive technologies (Dzardanova et al., 2018). While social virtual reality (VR) has already been integrated in previous studies (Barreda-Ángeles et al., 2023; Hein et al., 2023), a research gap exists in the fields of social augmented reality (AR) and social mixed reality (MR). Empirical research has highlighted potentials and challenges of educational processes involving the former (Lee & Hwang, 2022), making it worthwhile to examine these aspects for the other XR variants. Also, global dynamics have been increasingly intertwining cultures, bringing them closer together (Welsch, 1999). The associated concept of transculturality can be defined as "internal diversity, permeable borders, cultural blending and manifold cross-cultural connections" (Delanoy, 2012, p. 158). To address concomitant developments in a higher educational context, transcultural education is considered a valuable enhancement to media pedagogical concepts (Koponen, 2020). The current findings highlight the necessity to incorporate these perspectives into teaching and learning processes (Ripka et al., 2020; Smith, 2020).

Against this background, the researchers investigate the experiences of pre-service teachers across two German universities who participated in a teaching and learning scenario within a social MR environment that focused on transcultural education. Emphasizing their perceptions, anticipated opportunities, and challenges, the following research questions are posed:

- **RQ1:** How do pre-service teachers perceive teaching and learning processes in a social MR environment focusing on transcultural education?
- **RQ2:** What opportunities do pre-service teachers describe for teaching and learning processes in social MR environments focusing on transcultural education?
- **RQ3:** What challenges do pre-service teachers describe for teaching and learning processes in social MR environments focusing on transcultural education?

Literature Review

When analyzing teaching and learning processes, certain key components can be identified that are important to consider in favor of a systematic approach. In this context,

Tulodziecki et al. (2021) suggest *learning objectives and outcomes*, teaching and *learning activities*, and *technology* as central components of teaching and learning processes. Evaluating these components is also feasible when systematically analyzing teaching and learning processes focusing on transcultural education in social virtual environments.

Learning Objectives and Outcomes

Learning outcomes are the effects of learning objectives aimed at as "subject-relevant knowledge, skills, and abilities [...] with reference to guidelines, curricula, and educational standards [...]" (Tulodziecki et al., 2017, p. 195). Studies related to social VR environments have found that for this component, virtual environments, are often deemed a promising alternative to traditional instructional settings (Lee & Hwang, 2022). A study by Ripka et al. (2021) addressed pre-service teachers' development of technological pedagogical content knowledge (TPACK) within a social VR environment compared to a video conferencing platform. They observed that an action-oriented approach with complex tasks (Tulodziecki et al., 2021) in social VR promotes TPACK as a meta-conceptual awareness among pre-service teachers. Additionally, Hein et al. (2023) conducted a pilot study that indicated positive effects of social VR in enhancing inter- and transcultural competencies. In this study, pre-service teachers designed lessons for English learners at upper secondary schools considering intercultural perspectives and social VR environments (Hein et al., 2023). As a result, the participants expressed a preference for working with virtual avatars instead of virtual objects (Hein et al., 2023). Further, a study involving teacher educators demonstrated that social VR contributes to promoting intercultural media pedagogical skills through online dialogs with avatars or intercultural role-playing (Förster & Grafe, 2023). Educational research consistently underscores the potential of these environments to enhance learning outcomes across cognitive, skill-oriented, and affective learning objectives (Hamilton et al., 2020; Lee & Hwang, 2022). Among the benefits cited are increased motivation, creativity, and perceived enjoyment (Mystakidis et al., 2021; Phakamach et al., 2022).

Teaching and Learning Activities

Teaching activities are "characterized as practices of the teacher that aim to stimulate and support learning activities [which] can be described as mental and physical processes that are directed by the learners [...]" (Tulodziecki et al., 2017, p. 195). In this context, studies related to social VR environments have shown positive effects on collaboration and cooperation (Alam & Mohanty, 2022; Bower et al., 2020). Moreover, interactions between learners and between learners and teachers were both positively connotated (Alam & Mohanty, 2022; Bower et al., 2020; Lee & Hwang, 2022). From an intercultural perspective, social VR facilitates interactions in cultural contexts (Förster & Grafe, 2023), which allows drawing parallels with transcultural education. In this context, communication across geographical boundaries is cited as a key benefit in corresponding research (Freeman & Acena, 2021; Phakamach et al., 2022). Notwithstanding, challenges such as cognitive overload (Ripka et al., 2020) and the relative anonymity of avatar representations (Lin & Latoschik, 2022) can lead to disrespectful behaviors (Said, 2023), including cyberbullying as well as verbal and physical harassment (Blackwell et al., 2019; Mystakidis et al., 2021). The latter was explicitly identified for marginalized groups like ethnic minorities (Said, 2023). Moreover, the absence of social cues in these environments often results in communication challenges (Freeman & Acena, 2021).

Technology

Technology as a component of teaching and learning processes is either "used to support teaching activities or as a tool for learners [...] which should be used under consideration of the individual teaching phases and [...] other [...] components and conditions" (Tulodziecki et al., 2017, p. 196). Studies related to social VR environments have proven that the primary affordances of VR as technology are acknowledged as potential (Chen, 2023; Freeman & Acena, 2021), as they include immersive experiences, feelings of embodiment through avatar representation, and social copresence, which contribute to an increased sense of connectedness among users (Chen, 2023; Freeman & Acena, 2021). To promote transcultural media literacy in social virtual environments, Koponen (2020) calls for reflections on the technology from diverse sociocultural perspectives. However, drawbacks point to minor technical issues (Scavarelli et al., 2021), the need for extensive familiarization with both software and hardware (Barreda-Ángeles et al., 2023), and data protection challenges (Southgate et al., 2018). Health concerns such as cybersickness, feelings of fatigue, and negative emotions like frustration and boredom also pose obstacles (Mystakidis et al., 2021; Said, 2023). Moreover, the high costs of hardware, the complexity of technical implementation, and the necessity for media literacy are additional barriers (Garcia Estrada & Prasolova-Førland, 2021; Southgate et al., 2018). Lastly, the inability to monitor the physical environment while using head-mounted displays (HMDs) is recognized as a limitation compared to social AR (Nijholt, 2021).

In conclusion, based on the review of existing research, there is a desideratum to further examine pre-service teachers' perspectives on the central components of teaching and learning processes. This research aims to contribute to understanding how a pedagogical concept designed to foster pre-service teachers' media education competence in social MR, with a focus on transcultural education, should be designed and implemented.

Theoretical Framework: Pedagogical Concept

The theoretical foundation is based on the standard competence model for the first phase of initial teacher education in Germany by Tulodziecki (2012), which was selected from various media pedagogical models (Tiede, 2020). Here, media education competence is described as pre-service teachers' competence to support students in their acquisition of media literacy (Tulodziecki, 2012). According to this model, pre-service teachers are to acquire foundations for pedagogical target areas and to develop their own designs for teaching and learning scenarios "with media-related goals and content" (Tulodziecki, 2012, p. 291) in the academic phase of initial teacher education. The standard competence model offers various standards for each of these foundations and competence aspects. It also suggests the option to modify these standards for specific situations and groups (Tulodziecki, 2012). In this context, both transcultural education perspectives and social virtual environments can be integrated to meet the demands of the 21st century (Jurkova & Guo, 2018; Tulodziecki et al., 2021). Hence, the model selected is well-suited for Germany's two-phase initial teacher educator training.

The theory-based design of the study follows the principles of an action- and development-oriented pedagogical approach (Tulodziecki et al., 2021). This approach

incorporates complex tasks and a pre-defined structure for teaching and learning phases, divided into eight phases for media pedagogical activities (Tulodziecki et al., 2021). The specific focus of this study is on one of the five competence aspects of Tulodziecki's model, which involves the analysis and evaluation of pre-existing examples of media education lesson designs.

In this exploratory study, pre-service teachers from two German universities participated in a teaching and learning scenario implemented from January to March 2023. The aim was to pilot a segment of the pedagogical concept designed to enhance media education competence. The pre-service teachers were tasked with evaluating a given example of media education practice, particularly focusing on the opportunities and challenges associated with using social VR. The example centered on English lessons at the upper-secondary level, addressing media reports on discrimination in transcultural societies.

Following a flipped classroom approach (Al-Semarraie et al., 2020), the pre-service teachers were provided with an action-oriented script one week before the intervention (Figure 1), which included all phases leading up to the task solution. Participants independently acquired the necessary foundations and documented their initial solutions on a Padlet (www.padlet.com), a digital board for collecting and sharing content. After a brief technical familiarization, they refined the content and applied it to the task. The process concluded with comparing and summarizing solutions, followed by a focus group interview. The resulting teaching and learning process can be visualized as follows:

Figure 1

Visualization of Teaching and Learning Process

	Flipped Classroom	Social MR Environment		
1 week in advance	Task and spontaneous solutions	Technical familiarization	10 min	
	Agreement on objectives and significance	Flipped classroom revision	10 min	Teacher-centered phase
	Agreement on procedure	Task solution	30 min	Learner-centered phase
	Foundations for task solution	Comparison and summary	10 min	Teacher-centered phase
		Focus group interview	60 min	
		120 min		

Social MR Environment

The foundations for the design and implementation of the virtual classroom mainly build on location-independent teaching and learning scenarios (Freeman & Acena, 2021), both AR and VR participation (Nijholt, 2021), as well as further functionalities that are crucial to creating an interactive learning environment for pre-service teachers (Ripka et al., 2020). Therefore, an enhanced version of the *ViLeArn application* was used, based on the *Reality Stack Platform* (Latoschik et al., 2019). This version supports AR participation and VR participation. In this context, the teacher educator participated using the Varjo XR3, an MR device "that can switch between [here video see-through (VST)] AR and VR as necessary" (Speicher et al., 2019, p. 7). To move freely and operate flexibly within the classroom, the AR mode was activated for all the teaching activities. For this purpose, the dimensions of the virtual classroom were adapted to the

teacher educator's physical room, and both avatars and integrated features, such as virtual screens on the wall, were augmented. Co-located groups of pre-service teachers from each university, always separated from the teacher educator, used seated VR mode with the HP Reverb G2 Omnicept Edition. To align the virtual-to-physical environments in this MR scenario, all devices were calibrated at fixed locations before being handed over to the participants.

A theory-based combination of design features (Tulodziecki et al., 2021) set the ground for the development and implementation of the software and its functionalities. In this context, a clean design proved to be advantageous (Ripka et al., 2020). Figure 2 depicts the fully immersive VR view of the pre-service teachers in the social MR environment, which was kept clear and simple.

Figure 2

Visualization of Social MR Environment

Comic-like (stylized) avatars personalized with upper body features, gender, and names based on prior research by Kullmann et al. (2023) were chosen as virtual representations of the participants. To work interactively on the task solution, group workstations with virtual 3D models including numbered labels along with plus and minus symbols were provided for visualization purposes. Furthermore, virtual tablets, based on prior research from Kern et al. (2021), were integrated to facilitate internet browsing or accessing the online flipped classroom script. For notetaking, the collaborative open-source sketching tool "Excalidraw" was incorporated. Additionally, in-group screens were positioned on the virtual walls in front of the group workstations, enabling group members to share their virtual tablet view. The teacher educator had the same functionality on the opposite side of the virtual classroom.

Research Methodology

Study Context

The exploratory study was part of the project *ViLeArn_mor*e funded by the Federal Ministry of Education in Germany. The project focuses on virtual situated teaching and learning contexts with avatars and agents in social cyberspaces. One of the key objectives was to develop and implement pedagogical concepts in initial teacher education and evaluate the development of pre-service teachers' media education competence.

Sample

The study was conducted with a convenience sample of 15 pre-service teachers with little to no prior experience with VR technologies. The participants volunteered for this study without incentives in response to advertisements in teacher education courses, announcements on bulletin boards, and email distribution lists. Table 1 shows the socio-demographic data collected at the start of the intervention with an online questionnaire.

Table 1

Visualization of Sample Characteristics

Sample characteristics (n=15)		n	M	SD
Gender				
	Female	10		
	Male	4		
	Diverse	1		
Study program				
	Vocational training	4		
	Secondary school	3		
	Business education	3		
	Special needs school	2		
	Science education	2		
	Middle school	1		
Age (years)			26	4.7
Study progress (no. current semester)			5.7	4.2

Data Collection

Data was collected using focus group interviews as qualitative research elements (Krueger & Casey, 2015). The focus group guidelines were developed based on the central components of teaching and learning mentioned above, and the questions were:

- What experiences have you gathered in the social virtual environment?
- What experiences have you gathered during the group work in the social virtual environment?
- What experiences have you gathered during the plenary work in the social virtual environment?
- What opportunities do you expect for teaching and learning in the social virtual environment?
- What problems do you expect for teaching and learning in the social virtual environment?
- How would you use the social virtual environment in your future teaching?

The focus group interviews took place with a total of six groups, each consisting of two to three participants.

Data Analysis

The focus group interviews were recorded, anonymized, and transcribed using MAXQDA (Rädiker & Kuckartz, 2019). Two qualified researchers analyzed the interview transcripts by a qualitative content analysis (Mayring, 2015), applying the category system as described in Table 2.

Table 2

Visualization of Categories for the Qualitative Analysis

Superordinate categories	**Subordinate categories** applicable to all superordinate categories
1 Learner-centered perceptions of teaching and learning processes	1 Teaching and learning activities *a. Interaction Learner-Learner* *b. Interaction Lerner-Teacher*
2 Teacher-centered perceptions of teaching and learning processes	2 Technology *a. Software* *b. Hardware*
3 Opportunities for teaching and learning processes	3 Learning objectives and outcomes
4 Challenges for teaching and learning processes	

In a deductive approach, these categories were derived from the theoretical foundation of Tulodziecki et al. (2021). Superordinate and subordinate categories were abstracted from this source and then pretested. After discussion and reaching a consensus among several qualified researchers, minor adjustments were made, and a final category system was agreed upon.

Results

Pre-service teachers' perceptions, anticipated opportunities, and challenges of teaching and learning scenarios in social MR environments are presented for each main category under consideration of all four corresponding subordinate categories from Table 2 in Tables 3, 4, and 5. Key findings are highlighted in the sections that follow.

Teaching and Learning Activities

Notably, pre-service teachers collected contradictory experiences in the teaching and learning activities. While some participants perceived virtual interactions among learners as "seemingly natural" (Participant 1 (P1)), other participants reported significant communication challenges, such as the lack of turn-taking signals (P5) and non-verbal feedback (P2). Moreover, the study revealed the importance of the teacher educator's supportive role. With some participants "feeling left alone in [their] presentation" (P2), the teacher educator was perceived as sustaining, being "promptly available if needed for questions or advice" (P11).

Table 3

Visualization of Perceptions, Opportunities, and Challenges for Teaching and Learning Activities

Subordinate categories	**Superordinate categories**			
A Teaching and Learning Activities	**1** Learner-centered perceptions of teaching and learning processes	**2** Teacher-centered perceptions of teaching and learning processes	**3** Opportunities for teaching and learning processes	**4** Challenges for teaching and learning processes
a. Interaction Learner-Learner	**Aa.** + seemingly natural collaboration – difficult and slow interactions	**Aa.** *no explicit mentions*	**Aa.** + location-independent learning, + cultural exchange + international contact + counteracting bullying and exclusion	**Aa.** – co-located scenarios – reinforcement of prejudices – disrespectful behavior – difficulties in interactions
b. Interaction Learner-Teacher	**Ab.** + teacher's prompt availability + activating shared co-presence	**Ab.** – feeling unobserved/ left alone – particularly demanding	**Ab.** + remote experts + overcoming power relations + supporting pedagogical practices	**Ab.** – lacking respect and authority – impaired learner-teacher relationship – impaired classroom dynamics

Regarding opportunities for teaching and learning activities, social virtual environments were emphasized to enable location-independent learning for both learners and teacher educators (P6). As a student, "[...] you simply learn more when you really communicate with people from other countries [...] instead of [...] classmates [...] who grew up in the same society [...]" (P6). For teachers, remote participation as "specialist[s] who cannot be on site for whatever reason [...]" (P7) is facilitated. Moreover, uniformly designed avatars were particularly highlighted to promote inclusivity on different levels among students, as they can help engage specific target groups, such as shy or disabled learners (P3, P13, P15). From teachers and students, these avatars can contribute to overcoming power relations and breaking down established hierarchies (P14).

In terms of challenges, however, pre-service teachers expressed concerns regarding the alignment of external avatar appearances, as disrespectful behavior (P11) and prejudices could be reinforced (P14) when learners from different backgrounds interact with each other. P6, for instance, addressed that "the inhibition threshold is not as high as when I face [someone] personally." At the same time, this was associated with potentially impeding classroom dynamics (P3), potentially "shrinking [...] learner-teacher relationship[s]" (P14) needed for student socialization, especially for those "who are living in difficult conditions at home" (P9).

Technology

The study revealed striking contradictions in the experiences of pre-service teachers using the social MR software (Table 4). For learner-centered phases, the clean room design (P5) and the 3D model were praised as "futuristic" (P11) and "exciting" (P13). Still, some participants found the 3D model "superfluous" (P12) and "distracting" (P9). For teacher-centered phases, the intuitive handling of virtual tablets and screens was lauded (P4); yet, this was contradicted by frequent challenges such as "motoric limitations, mistyping [...], longer duration[s]" during reading and writing activities (P6). Additionally, through the use of VR mode for participants, a lack of mobility within the virtual space made the participants feel "trapped on the chair" (P5), which impeded interactions with integrated features and limited options for repositioning in the

room. This notion was one of the most frequently stated challenges of the technology foreseen for educational processes.

Table 4

Visualization of Perceptions, Opportunities, and Challenges for Technology

Subordinate categories	Superordinate categories			
B Technology	**1** Learner-centered perceptions of teaching and learning processes	**2** Teacher-centered perceptions of teaching and learning processes	**3** Opportunities for teaching and learning processes	**4** Challenges for teaching and learning processes
a. Software	**Ba.** + clean room design + combination of features – lacking physical mobility *3D model* + futuristic visualization tool – superfluous and distracting *virtual tablets* + intuitive handling – motoric limitations	**Ba.** – untouched *3D model* + high value of *virtual screens*	**Ba.** + diverse learning scenarios + exploration and experimentation + stimulation of senses	**Ba.** + diverse learning and practice scenarios + exploration and experimentation + stimulation of senses
b. Hardware	**Bb.** – minor technical problems	**Bb.** – minor technical problems	**Bb.** *no explicit mentions*	**Bb.** – availability, set up, cost – potential addiction and misusage – physical discomfort – unequal accessibility

Besides, further inclusive concerns were prominent in the focus groups. Pre-service teachers commented on "potentially widening gaps accompanied by unequal chances [among] children across [different educational backgrounds]" (P9). Nevertheless, regarding opportunities of social virtual environments, participants still saw outstanding potential in multifold learning scenarios. These included, for instance, practicing with "pre-programmed avatars" (P9), engaging with "virtual [...] contemporary witnesses" (P8), participating in "virtual trips" (P13), or experimenting "beyond dangerous situations" (P2).

Learning Objectives and Outcomes

It is notable that pre-service teachers did not explicitly address learning objectives and outcomes when reflecting on their own experiences in the social MR environment (Table 5). Also, statements about opportunities and challenges associated with this component were sparse. Participants underscored the potential for the acquisition of certain competencies, such as media skills, intercultural skills, foreign language skills, social skills, and communication skills. P11, for instance, said: "You can promote certain competencies in the same way as you can [...] do [...] in the [regular] classroom" (P11). P13 further elaborated on this: "[...] it is such a special learning setting, children [...] will remember it better; [...] [hence, children can] dive in deeper". Conversely, apprehensions emerged regarding the feasibility of achieving learning objectives in social MR environments. For instance, P12 highlighted that the acquisition of "social skills" might be hindered or even impossible due to the limiting communication processes within these environments.

Table 5

Visualization of Perceptions, Opportunities, and Challenges for Learning Objectives and Outcomes

Subordinate categories	Superordinate categories			
C Learning objectives and outcomes	**1** Learner-centered perceptions of teaching and learning processes	**2** Teacher-centered perceptions of teaching and learning processes	**3** Opportunities for teaching and learning processes	**4** Challenges for teaching and learning processes
	C. *no explicit mentions*	**C.** *no explicit mentions*	**C.** + analogies to real-world settings + facilitated acquisition of skills + deeper learning + improved memory performance	**C.** – cognitive overload – impaired concentration – overwhelming experience – hindered acquisition of skills

Discussion

RQ1: *How do pre-service teachers perceive teaching and learning processes in a social MR environment focusing on transcultural education?*

Regarding RQ1, the qualitative analysis revealed that pre-service teachers perceived the social MR environment as a promising alternative to traditional settings of teaching and learning. These results align with prior findings on social VR environments (Ripka et al., 2020). The co-presence of the teacher educator was highlighted as pivotal in activating pre-service teachers, which may have been amplified by the freedom of movement in teaching activities when using AR mode. Participants expressed precise preferences for increased mobility within the virtual classroom. This suggests the importance of embedding AR or MR mode for both teachers and learners in future studies (Nijholt, 2021). Furthermore, participants emphasized the effectiveness of interaction, collaboration, and task sharing, especially among learners. However, as noted in Freeman and Acena (2021), the participants recognized impairments in communication due to the absence of signals for turn-taking in social MR. This was particularly evident when comparing and summarizing in the plenary setting. Regarding technology, pre-service teachers described the software design as clean with little potential for distraction, suggesting its suitability for comparable scenarios in higher education contexts. Participants, however, demonstrated heterogeneous perceptions of the functionality of integrated features. Moreover, minor technical challenges related to the hardware were reported, likewise consistent with previous findings on social VR (Southgate et al., 2018). This highlights the importance of pre-service teachers' media literacy as well as technical support. Additionally, this study revealed that learning objectives and outcomes, as well as aspects of transcultural education, were predominantly omitted within experience reports unless explicitly prompted. This observation suggests that they potentially marginalize these elements when reflecting on their own learning processes.

All in all, pre-service teachers perceived social MR as a promising alternative to traditional and social VR settings. They emphasized effective interaction and collaboration but noted communication challenges, heterogeneous perceptions of integrated media features, and the need for media literacy and technical support to eventually achieve learning outcomes.

RQ2: *What opportunities do pre-service teachers describe for teaching and learning processes in social MR environments focusing on transcultural education?*

Cultural exchange, international contact, and location-independent learning were identified as core potentials for teaching and learning scenarios in social MR environments focusing on transcultural education (Phakamach et al., 2022). Additionally, pre-service teachers listed inclusive aspects as feasible benefits, such as mitigating discrimination against outsiders or dismantling power structures within the classroom hierarchy through avatar embodiment. Furthermore, pedagogical potentials such as action-oriented and learner-centered teaching and learning processes in the social MR classroom were uncovered in the qualitative analysis, which resonates with existing research on social VR (Ripka et al., 2020). Social MR's potential regarding learning objectives and outcomes, for instance, encompassed media literacy as well as intercultural competence, aligning with results from previous social VR studies (Koponen, 2020; Lee & Hwang, 2018). Nonetheless, pre-service teachers did not draw direct linkages between transculturality and media literacy as a result of the intervention. This suggests potential reference points for developments in future pedagogical concepts. Regarding technology, the participants primarily discussed opportunities related to the software rather than the hardware. They recognized, for example, the potential to create effective learning experiences as well as safe spaces for social experiences, exploration, and additional practice.

In conclusion, pre-service teachers identified social MR as beneficial for diverse learning scenarios to realize, for instance, cultural exchanges or to foster certain competencies. Moreover, they recognized its potential for action-oriented and learner-centered teaching and learning processes in safe learning spaces.

RQ3: *What challenges do pre-service teachers describe for teaching and learning processes in social MR environments focusing on transcultural education?*

As regards RQ3, the sample expressed skepticism about the actual effectiveness of social virtual classrooms in general to achieve learning objectives and outcomes. Participants, in particular, pinpointed obstacles to acquiring social skills. Additionally, the findings revealed concerns attributed to the relative anonymity of avatars and the absence of social cues (Lin & Latoschik, 2022). More specifically, pre-service teachers noted the prevalence of communication challenges, especially in larger groups of students. In this context, challenges regarding the teacher-learner relationship were also identified. Apart from this, concerns were raised about the potential reinforcement of prejudices during international exchanges, indicating de novo a desideratum for intertwining transcultural education with media literacy. In conjunction with this, pre-service teachers touched upon their concerns about insufficient media literacy among both learners and teachers and emphasized the relevance of reflections on media usage within the teaching and learning process. Referring to technology usage itself, health concerns such as cyber sickness or negative emotions were mentioned, consistent with prior findings on social VR (Mystakidis et al., 2021). Institutional challenges, such as financial dispenses or set-up efforts (Southgate et al., 2018), were also identified as potential hurdles in this regard, which need to be considered in future interventions.

Finally, some pre-service teachers questioned social MR's effect on learning outcomes, highlighting challenges in teaching and learning activities such as communication in larger groups. Apart from that, they raised concerns about technology-related issues such as lacking media literacy or certain health risks associated with social VR.

Conclusion and Outlook

In summary, the findings of this study provided pedagogical implications for future initial teacher education practice and research. They are based on pre-service teachers' experiences as well as anticipated opportunities and challenges for teaching and learning in social MR focusing on transcultural education. In this context, pre-service teachers perceived the social MR environment, on the one hand, as a promising instructional setting, emphasizing experiences of effective collaboration among themselves and with integrated media features. On the other hand, they noted the need for improved communication processes, technical support, and more freedom of movement such as provided for the teacher educator (RQ1). Furthermore, the sample primarily viewed the social MR environment as an opportunity for location-independent interaction and cultural exchange, but also as a beneficial setting for social experience and practice beyond traditional classroom limitations (RQ2). Nevertheless, participants highlighted challenges, including the lack of media-related competencies among teachers and learners for effective deployment, potential obstacles in transcultural contexts such as reinforcing prejudices, commonly-known health concerns, and unfavorable institutional conditions (RQ3).

For future pedagogical concepts, this exploratory study constitutes a prototype seminar unit that serves as a basis for developing seminars for the initial phase of teacher education throughout an entire semester. Extending the concept would provide the opportunity to not only explore one competence aspect of the competence model applied and to systematically address and promote several competence aspects. It is also desirable to further intertwine considerations of transcultural education with media educational perspectives. To provide an instructional setting for this, the current version of the social virtual environment seems suitable. Nevertheless, minor enhancements, such as further group workstations to support larger groups of learners or demarcations between learners and teachers, could be expedient. Because findings also indicated concerns about co-located settings, this aspect should be further examined in future teaching and learning scenarios. In this context, enabling access to AR-capable devices and, hence, physical freedom of movement for all could prove beneficial. However, to minimize technical challenges, institutional frameworks, as well as options for technical support and habituation phases, appear to be remarkable.

For future educational research, prospective studies should examine empirical effects and measurable learning outcomes regarding the development of media education competence among pre-service teachers. Therefore, larger samples and longer intervention periods might prove beneficial in such studies. Moreover, comprehensive considerations of theoretical and empirical foundations to design teaching and learning scenarios for the higher education context are to be comprised. Ultimately, interdisciplinary research suggests facilitating the transfer of findings to diverse contexts and may contribute to enhancing pre-service teachers' media education competence using social MR environments, with a focus on transcultural education.

Limitations

The findings of this study must be considered against the background of the following limitations. First, due to the research design, no conclusions can be drawn about measurable learning outcomes. The focus was on capturing participants' perspectives in an exploratory sense to identify the target group's subjective impressions relevant for future pedagogical concepts. Second, a small convenience sample was being examined within limited intervention periods. Besides, contributions in the focus group discussions may have been influenced by social desirability. Third, technical constraints as well as high demands for support led to a restriction of teaching activities to AR mode while learning activities were realized in VR mode. This implies that pre-service teachers had limited opportunity to familiarize themselves with the social environment in AR mode.

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Acknowledgments

This study was part of the research project *ViLeArn_more,* funded by the German Federal Ministry of Education under the funding line “Research on digital higher education” (reference number 16DHB2214). We thank Peter Kullmann and Florian Kern from the University of Wuerzburg for providing the platform used in this study, adapting it to our research context, and assisting in setting up the apparatus. Moreover, we thank Laura Pflieger from the Technical University of Munich for her cross-university collaboration, recruitment, and supervision of participants.

FOUR PILLARS OF TECHNOLOGY INFUSION: USING Q METHODOLOGY TO EXAMINE CANDIDATE PERSPECTIVES ON THEIR PREPARATION TO USE TECHNOLOGY

Jon M. Clausen
Ball State University, USA
jmclaus@bsu.edu

David Rutledge
New Mexico State University, USA

Arlene C. Borthwick
National Louis University, USA

Shannon Driscoll
University of Dayton, USA

Yi Jin
Kennesaw State University, USA

Debra R. Sprague
George Mason University, USA

Melissa Warr
New Mexico State University, USA

Mia Kim Williams
University of Wyoming, USA

Abstract. Technology infusion has been proposed as essential in preparing teacher education candidates to use technology within their own instructional practices. Foulger (2020) articulated four pillars needed for technology infusion. These include the educator preparation program (EPP) curriculum, candidate beliefs and efficacy, how technology has been modeled by faculty, and whether candidates have had opportunities to critically think about and use technology throughout their preparation, including within clinical practice. This study examines teacher education candidates' perspectives about their preparation to use technology within their respective EPPs. Q methodology and factor analysis were used to identify how candidates (N=90) from seven institutions across the United States characterized their preparation as aligned with the four pillars of technology infusion in teacher preparation.

Keywords. Q Methodology, Technology Infusion, Technology Integration, Teacher education,

Introduction

While government agencies and professional organizations continue to advocate for increased efforts to prepare teacher candidates (TCs) to use educational technology, this goal remains elusive. A recent summary of research by the International Society for Technology in Education (ISTE) highlights ongoing issues in preparing teachers to use technology (ISTE, 2023). Three key findings include:

- … the urgent need for greater faculty expertise in digital pedagogy to drive formative change…
- … new teachers lacked confidence using learning technologies…
- … a need for greater breadth, depth, and quality to facilitate preservice teachers' development of digital pedagogy skills. (p.3)

ISTE survey results emphasized the need for faculty to model digital pedagogical skills, with only 9% of educator preparation programs (EPPs) reporting that every faculty member embraces and models instructional technology. A separate survey, described by ISTE (2023) and attributed to Jenna Conan Simpson, indicated 56% of TC participants lacked confidence in using learning technologies effectively. These ongoing challenges suggest the need for a new paradigm and an evaluation of how TCs are prepared to use educational technology within their instructional practice.

Literature Review and Conceptual Framework

Technology infusion has been proposed as a new paradigm for preparing TCs to integrate technology for teaching and learning (Williamson et al., 2023). Emerging from federal calls for technology to be used program-deep and program-wide within educator preparation (DOEOET, 2017), researchers focusing on technology infusion have challenged EPPs to improve and expand opportunities for candidates in support of PK12 content area learning (Borthwick et al., 2020). Williamson et al. (2023) identified ten characteristics and indicators of technology-infused programs that include: pervasive technology content; shared responsibility; unified vision; planned curriculum; developmental practice-based approach; varied, multi-stage assessment for continuous improvement; informed design and renewal; technology competent teacher educators; ubiquitous access; and leadership support for systemic change. These ten characteristics provide valuable guidance for developing a more fully infused curriculum for EPPs. They conclude, "... a community of practice dedicated to studying and sharing their cyclical design experiences will advance the cause and produce multiple ways of achieving program-deep and program-wide approaches to teacher technology preparation" (p. 221).

Foulger (2020) identified four pillars specific to designing technology infused programs. The four pillars include technology integration curriculum, modeling technology integration, practice and reflection, and development of technology self-efficacy. As such, these pillars served as the conceptual framework for our investigation of TCs' perspectives on their preparation to use technology for teaching and learning. A special issue of the *Journal of Contemporary Issues in Technology and Teacher Education* (Volume 23, Issue 1, 2023) provided literature summaries related to each of the four pillars of technology infusion, which are

described below (Graziano et al., 2023, Jin et al., 2023; Sprague et al, 2023, Warr et al., 2023; Williams et al., 2023).

Pillar One emphasizes the need for careful design of a technology infused curriculum. The curriculum includes the content—standards, core values, and contextual knowledge. A curricular plan should also include situated practice (in content areas and professional communities) and "touchpoints"—carefully sequenced opportunities for TCs to observe and use effective technology integration practices. These touchpoints can spread across the curriculum, including in foundational educational technology courses, methods courses, clinical experiences, etc. When designing a technology infused curriculum, it is critical to consider the EPP and community context, including the values, history, needs, and policy of the program and community. The design process should enable continual evaluation and be responsive to shifting contexts, including technological progress.

Pillar Two examines how modeling technology integration is a useful and much-needed strategy in teacher education programs (e.g., Sardone, 2019; Tondeur et al., 2018). Jin et al. (2023) analyzed 65 articles and proposed a new modeling design, as well as research-based principles, implementation strategies, and teacher educator competencies. Well-designed modeling strategies can bring positive outcomes (e.g., Cheng et al., 2022; Neumann et al., 2021; Zipke et al., 2019). However, modeling should not be a single strategy. Instead, it is usually a combination of various strategies joined together in a sequence due to design considerations. Thus, it is necessary to examine the design of modeling instructional technology integration in EPPs to guide practice.

Pillar Three focuses on clinical practice along with university-school partnerships. This pillar emphasizes how school contexts can enhance opportunities for TCs to plan and teach with technology while also reflecting on those experiences (Sprague et al., 2023). Based on AACTE's 2018 synthesis of research and recommendations for clinical practice (Clinical Practice Commission, 2018), Sprague et al. (2020) identified specific applications supportive of technology-infused clinical practice. School-based experiences help TCs to develop the knowledge, skills, and self-efficacy to integrate technology into their practice. To effectively support candidates in the field, EPPs and PK12 schools must work together to establish and implement a unified vision of how to teach with technology.

Pillar Four refers to Teacher Self-Efficacy in Technology Integration (TSEinTI), teachers' confidence in their ability to integrate technology into classroom teaching and learning successfully. This concept was developed from a synthesis of relevant literature about the influences of teacher preparation to use technology, such as environments, attitudes, beliefs, support, and resources. It describes how teacher preparation can promote TSEinTI through programs that (1) provide authentic experiences requiring candidates to design technology-integrated lessons, (2) incorporate reflective practices, and (3) assess candidate growth in TSEinTI (Williams et al., 2023). Program culture and leadership also play a key role in establishing expectations for faculty to model technology, providing infrastructure and equitable access to technology, and developing teacher educators' technology competencies. Adopting an infusion approach will support TCs' development to effectively leverage technology in their future classrooms.

With the four pillars as a conceptual framework, the following research questions guided our inquiry.

- RQ1: What are teacher education candidates' perspectives about the design of their educator preparation program to integrate technology and instructor modeling and opportunities for practice? (Pillars One & Two)
- RQ2: What are teacher education candidates' perspectives on how EPPs implement field placements to support candidate development to use educational technology? (Pillar Three)
- RQ3: What are teacher education candidates' beliefs about the value of educational technology and their self-efficacy in using it for teaching and learning? (Pillar Four, TSEinTI)
- RQ4: How might Q methodology serve as a tool for teacher education candidates to provide feedback on their technology education? (Factor Analysis)

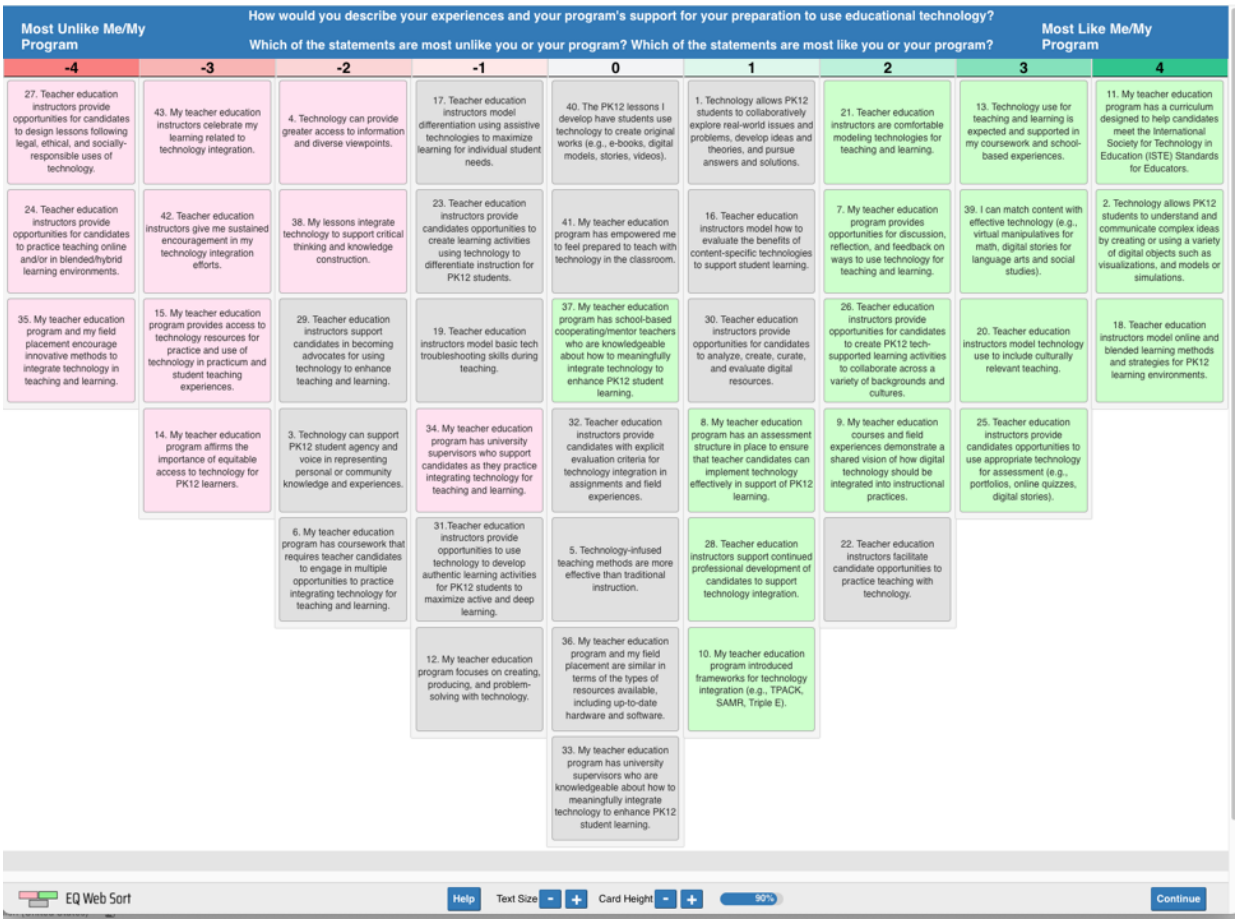
Methods

This study used a mixed methods approach involving Q methodology (McKeown & Thomas, 2013; Stephenson, 1935, 1953) coupled with collection of demographic and qualitative responses. Participants were asked to complete a forced Q sort of 43 statements (Appendix A) aligned with the four pillars of technology infusion in teacher preparation. The statements were based on prior research (Clausen et al., 2023). The statements were reviewed and revised with the lead authors of literature summaries published in 2023 (Jin et al., 2023; Sprague et al, 2023, Warr et al., 2023; Williams et al., 2023) during a series of meetings over a period of several months. The final number of statements aligned with each pillar varied: 10 statements for Pillar One, 17 statements for Pillar Two, 5 statements for Pillar Three, and 11 statements for Pillar Four.

Using EQ Web Sort (Banasick, 2022), participants completed a forced sort that required a selected number of statements to be placed in nine columns across a continuum from -4 (most unlike their beliefs and experiences) to +4 (most like their beliefs and experiences). Participants were then asked to provide a brief rationale for their placement of statements in the -4 and +4 columns. The entire process – from review and signature of a consent form to submitting the Q sort and demographic and qualitative responses – was completed online. Figure 1 is an image from EQ Web Sort that shows a completed forced sort of statements with the colors representing a participants' initial thoughts: red for unlike them, grey for neutral, green for like them.

Figure 1

Image of Sample Completed Forced Q Sort (-4 to +4) Using EQ Web Sort



Data Sources

Participants in this study came from seven institutions, five public and two private, across the United States. A majority of them were from undergraduate EPPs and majoring in early childhood, elementary education, and secondary education. All participants were enrolled in or had recently completed their final practicum before student teaching. There were 90 total participants with a range from 2 to 27 TCs from each institution.

Data Analysis

The authors examined data in multiple ways: the correlation of participant sorts with one another to identify groups of similar participants (factors) (Watts & Stenner, 2012), pillar-aligned statements placed at the -4 and -3 end of the continuum contrasted with the statements placed at the +4 and +3 end of the continuum for a specific pillar, and number of candidates from a single institution sorting in similar ways. KADE software (Banasick, 2021) was used to identify factors via varimax rotation and principal components analysis. EQ Web Sort (Banasick, 2022) provided

a file with participants' qualitative responses. A Google form was used to collect and review demographic data.

Results

Findings across all EPPs were compiled and analyzed in alignment with the four pillars of technology infusion. To address the first three research questions, results for each of the four pillars are presented with a brief summary of the data most strongly aligned with TCs' perspectives of beliefs and experiences during their preparation programs.

Pillar One emphasizes the need for thoughtful design of a technology infusion curriculum, and 10 statements (QS6-15) were aligned with this pillar. Table 1 presents the statements with the highest frequencies of "Most Unlike" and "Most Like" TC responses from the 90 participants in this study.

Table 1

Frequency of Responses in the Q Sort (-4, -3, +3, +4) for Selected Statements Aligned with Pillar One

Q Statements	Most unlike me		Most like me	
	-4	-3	3	4
7. My teacher education program provides opportunities for discussion, reflection, and feedback on ways to use technology for teaching and learning.	0	4	11	11
8. My teacher education program has an assessment structure in place to ensure that teacher candidates can implement technology effectively in support of PK12 learning.	11	12	2	4
10. My teacher education program introduced frameworks for technology integration (e.g., TPACK, SAMR, Triple E).	44	5	5	3
11. My teacher education program has a curriculum designed to help candidates meet the International Society for Technology in Education (ISTE) Standards for Educators.	17	14	5	2
13. Technology use for teaching and learning is expected and supported in my coursework and school-based experiences.	3	7	16	8
14. My teacher education program affirms the importance of equitable access to technology for PK12 learners.	3	4	10	9

Q sorts submitted by the participants presented particularly negative perspectives related to assessment structures within their EPP (QS8), implementation of technology integration frameworks (QS10), and curriculum intended to meet ISTE standards (QS11). TCs' reasons for the placement of these statements in the -4 column (Most Unlike me/my experiences) illustrate their responses related to this pillar.

- "We do not have an assessment structure in place to ensure that we are implementing technology" (MW1A3).
- "I have never heard of TPACK, SAMR, Triple E or any other framework for tech integration in the teacher education program" (W2W07).

- “I do not believe we have any curriculum designed for Technology in Education Standards for Educators and I'm honestly not too sure what that even is because it has not been talked about at my university” (MW3A6).

On the other hand, TCs’ Q sorts represented more positive feedback related to program opportunities for reflection and feedback (QS7), program expectation for use of technology by TCs in coursework and field experiences (QS13), and affirmation of the importance of PK12 learner equitable access to technology (QS14). TCs stated:

- “Many of our in-class conversations centered on how we can use technology not only to reflect on goals and previous work as well as how we can use technology to have students reflect on their viewpoints” (W2T02).
- “Many of our assignments use a form of technology. We use it during class for homework and many different teaching resources. It is expected that it is part of our lessons and coursework” (MW3A8).
- “All of my courses are based in equitable access to education. Technology is a learning tool that we have discussed and those discussions were based in equitable access to tech for students” (E1S1).

Pillar Two encompasses descriptions of how teacher educators can model technology integration across various learning environments TCs may encounter, and 17 statements (QS16-32) were aligned with this pillar. Three statements representing key areas of focus were statements 19, 24, and 32. Table 2 represents the Pilar Two statements with the highest frequencies of “Most Unlike” and “Most Like” TC responses from the 90 participants in this study.

Table 2

Frequency of Responses in the Q Sort (-4, -3, +3, +4) for Selected Statements Aligned with Pillar Two

Q Statements	Most Unlike Me		Most Like Me	
	-4	-3	3	4
19. Teacher education instructors model basic tech troubleshooting skills during teaching.	*25*	*14*	4	2
24. Teacher education instructors provide opportunities for candidates to practice teaching online and/or in blended/hybrid learning environments.	*15*	*16*	4	3
32. Teacher education instructors provide candidates with explicit evaluation criteria for technology integration in assignments and field experiences.	*6*	*17*	1	2

Q sorts submitted by the participants did not rate modeling as a strong characteristic of their programs. Among the 17 statements related to modeling technology use, three statements (QS19, 24, 32) were identified among the “Most Unlike” ratings. These three statements center on instructor modeling of technology troubleshooting (QS19), creating opportunities for candidates to practice in blended/online learning contexts (QS24), and explicit assessment and evaluation criteria for technology integration (QS32). Qualitative comments verified these findings through the TCs’ descriptions of how some instructors were not comfortable with modeling technology integration and held negative attitudes toward technology integration.

- “I have never seen a professor or instructor model troubleshooting. It seems as if I am expected to know or learn for myself” (E268).
- “Currently there is not an opportunity to practice teaching online in my location. Most schools are no longer providing online or hybrid learning except for specific schools that are designed to be online” (MW2A1).
- “I can only think of one time where we had to incorporate technology into a lesson however we did not actually use the program just say how we would use it. Other than that I have not been told that I have to use technology for anything” (MW3A3).

Pillar Three comprises the design and support of iterative practice and reflection during clinical practice, and five statements in the Q sort (QS33-37) were aligned with this pillar. Key statements included QS 33, 36, and 37, based on responses from the 90 teacher candidates in the study. Table 3 presents statements with the highest frequencies of “Most Unlike” and “Most Like” teacher candidate responses.

Table 3

Frequency of Responses in the Q Sort (-4, -3, +3, +4) for Selected Statements Aligned with Pillar Three

Q Statements	Most Unlike Me		Most Like Me	
	-4	-3	3	4
33. My teacher education program has university supervisors who are knowledgeable about how to meaningfully integrate technology to enhance PK12 student learning.	6	11	4	4
36. My teacher education program and my field placement are similar in terms of the types of resources available, including up-to-date hardware and software.	7	12	6	4
37. My teacher education program has school-based cooperating/mentor teachers who are knowledgeable about how to meaningfully integrate technology to enhance PK12 student learning.	5	14	9	3

TCs often identified negative perspectives of their opportunities to practice teaching with technology. They indicated that university supervisors and mentor teachers were not knowledgeable in how to meaningfully integrate technology to support K12 student learning (QS33, 37) and that there were differences between the technology available at the university and at the PK12 school-based environments (QS36).

- “The program does not always teach effectively about how to integrate technology to enhance to student learning they just state its important” (E249).
- “My field placement has technology that is out of date compared to my university” (MW1A11).
- “My mentor teachers haven’t really incorporated much technology” (MW1A8).

Pillar Four explicates the TCs’ beliefs regarding the value of technology for learning and the development of their self-efficacy in technology integration (TSEinTI), and 11 statements aligned with this pillar (QS1-5 and 38-43). Table 4 highlights six key statements with the highest

frequencies of "Most Unlike" and "Most Like" TC responses from the 90 participants in this study.

Table 4

Frequency of Responses in the Q Sort (-4, -3, +3, +4) for Selected Statements Aligned with Pillar Four

Q Statements	Most Unlike Me		Most Like Me	
	-4	-3	3	4
1. Technology allows PK12 students to collaboratively explore real-world issues and problems, develop ideas and theories, and pursue answers and solutions.	4	0	15	23
2. Technology allows PK12 students to understand and communicate complex ideas by creating or using a variety of digital objects such as visualizations, and models or simulations.	0	5	14	16
3. Technology can support PK12 student agency and voice in representing personal or community knowledge and experiences.	1	8	11	14
4. Technology can provide greater access to information and diverse viewpoints.	0	2	20	31
38. My lessons integrate technology to support critical thinking and knowledge construction.	2	7	14	10
39. I can match content with effective technology (e.g., virtual manipulatives for math, digital stories for language arts and social studies).	5	5	16	14

Participants loaded strongly in "Most Like Me" in relation to six statements (QS1, 2, 3, 4, 38 and 39). These statements are about TCs beliefs and efficacy, and how those perspectives influence their technology integration practices.

- "Using technology in the classroom allows students to explore beyond the textbook and the bubble that they live in every day (W2T03).
- "I think it is so important that we use technology because it allows us that discussion. There are so many different perspectives in the world that it's important that we hear from each-other and are able to open up that discussion (MW1A13)"
- "I am always open to trying something new that may be more exciting for students especially with the support of my cooperating teachers" (MW3A9).
- "I feel that I am able to do this based off of the training that I went in [sic] the past four years." (MW1A17).

To address the fourth research question, we completed a statistical analysis of the 90 Q sorts collected across seven institutions. Using KADE Software (Banasick, 2021), we identified four factors, with 67 participants loading on a factor. Table 5 includes the number of participants loading on each factor, ranging from 35 on Factor A, 14 on Factor B, to 9 on Factors C and D. Both Factors C and D had participants who loaded in a bipolar manner—indicating the same Q statements were important—but with a "mirror image" configuration (Watts & Stenner, 2012). Following Table 5, we briefly summarize each factor based on our review of distinguishing statements and exemplary sorts for each factor plus explanations from participants for statements placed at the +4 or -4 ranks. A full report of the factor analysis and related implications will be provided in a future manuscript.

Table 5

Participant Perspectives Identified Through Factor Analysis

Factor	Brief Description	Participants Loading	Bipolar Participants	Institutions Represented
Factor A	Strong TSEinTI	35	0	6
Factor B	Disconnect of Coursework and Field Experiences	14	0	6
Factor C	Encouraged Yet Unconvinced	9	2	3
Factor D	Supported but More to Learn re. Tech Integration	9	3	4

Factor Summaries

Strong TSEinTI

The Q sorts completed by the 35 participants who loaded on Factor A revealed teacher candidate confidence in integrating technology for critical thinking and knowledge construction (+3), and development of lessons for PK12 creation of original works (+1). Results also reflected EPP curricular design with a shared vision (+2) and program expectations and support for technology use in courses and field experiences (+3).

Disconnect of Coursework and Field Experiences

Although Q sorts completed by participants on this factor suggested expectations for technology use (+1) and support for candidate evaluation, curation, and creation of digital resources (+3), Factor B participants noted a lack of shared vision across courses and field experiences related to technology integration (-4). Results also showed a lack of knowledgeable cooperating/mentor teachers and university supervisors (-2) and access to technology resources in the field (-2).

Encouraged Yet Unconvinced

Q sorts completed by these participants suggested that candidates felt sustained support and encouragement (+4) and empowered to undertake technology integration efforts (+2). However, Q sorts completed by these participants reflected less opportunity (-2) and lower expectation and support (-3) for practicing technology integration. They also did not believe that tech-infused teaching methods were more effective than traditional methods (-3). As this was a bipolar factor, several participants who loaded on this factor had opposing rankings of these same Q statements.

Supported but More to Learn re. Tech Integration

Participants on this factor indicated expectations, opportunities, and support were prominent (+4). They also had instructors who both modeled (+3) and provided opportunities for them to practice teaching in online/hybrid learning environments (+4). Nevertheless, they did not

identify skill in matching effective technology with content matter (-4), or program focus on using technology for problem-solving (-3), or their own lessons integrating technology for critical thinking and knowledge construction (-2). As this was a bipolar factor, several participants who loaded on this factor had opposing rankings of these same Q statements.

Discussion and Implications

Factors represent varied viewpoints across the 90 participants, but also across participants at a single institution. We observed that at six of the seven institutions, TCs loaded on several different factors. In fact, the three institutions with the largest number of participants had TCs that loaded on four different factors; based on their Q sorts, not everyone's perceptions correlated strongly with others attending the same institution.

Further, in examining placement of Q statements for Pillar One (QS6-15), we found responses from TCs at the same institution often represented a range of rankings. For example, at one institution (E2) candidate responses were at *every* rank from -4 to + 4 for QS6, 10, 11, and 14. Thus, it seems clear that candidates were not having consistent experiences at their institution in terms of opportunities to practice technology integration, instruction related to frameworks for technology integration, curriculum to meet the ISTE standards, and affirmation of the importance of PK12 equitable access to technology. The disparate and inconsistent responses of participants within other institutions were also evident.

Statistically significant consensus items across all four factors included QS17, 19, and 26. Two of these were placed at 0 or -1. More revealing was QS 19, instructor modeling of basic tech troubleshooting skills during teaching, which was placed at -3 or -4 by all four factors. Perhaps teacher educators primarily use hardware and software with which they are very familiar, call on university or college tech support when they experience difficulty, or avoid using new or complex tools. Though not statistically significant, on a more positive note, all four factors placed QS 7, provision of opportunities for discussion, reflection and feedback on ways to use technology for teaching and learning, at +1 (Factor A) or +2 (Factors B, C, and D).

The four-factor solution also revealed seven items (QS1,11, 13, 24, 25, 39, 40) where factor rankings ranged from -4 to +3 or +4, or -3 to +4. These included statements about curriculum designed to meet the ISTE Standards, TC opportunities to practice teaching online and/or in blended/hybrid learning environments, expectation and support for technology use in courses and field work, and ability to match effective technology with content matter. Once again, TC responses reveal very different experiences in their preparation to use technology for teaching and learning. Further, these items represent technology infusion via program elements within Pillars One, Two, Three, and Four.

Conclusion

Prior research about teacher education faculty and candidates using Q methodology (Clausen et al., 2021, 2023, 2024) identified EPPs' lack of a structured technology-infused curriculum and assessment system designed to address standards and frameworks. As stated by one participant in the current study, "I don't believe I have been assessed on implementing technology at all" (E1S8). Curriculum design, the modeling pre-service teachers receive, technology-infused clinical practices, and development of candidate efficacy are all dependent

on the contextual factors and the stakeholders with whom candidates interact. Williamson, et al. (2023) categorize technology infusion in teacher preparation as a "new paradigm," and adoption of the paradigm as a challenging endeavor requiring the participation of a community of inquiry and practice. Broad stakeholder involvement to address the four foundational pillars examined in our study requires agreement on competencies and expectations to be met by TCs (e.g., licensure requirements), faculty role models, and field-based mentors and supervisors, and the steps to build individual and community-wide commitment to achieving change (South & Song, 2020). Tables and checklists provided in the CITE 2023 journal pillar summaries (Jin et al., 2023; Sprague et al, 2023; Warr et al., 2023; Williams et al., 2023) provide considerations for how to design, improve, or expand essential program elements to assure the development of candidate knowledge, skills, and dispositions.

Results from our study highlight a continued lack of consistency in the implementation of the four pillars for technology infusion within EPPs. We found inconsistencies related to a cohesive curriculum design, faculty modeling, and clinical practice opportunities. Leadership by EPP faculty and administrators in close coordination with other stakeholders can assure the implementation of a shared vision and systematic processes for technology infusion, with the goal of transforming how TC's are prepared to use technology in their future classrooms. Teacher education faculty must have the resolve to develop instructional contexts and curriculum that focus on the deliberate development of TCs self-efficacy in technology integration, a paramount component in achieving technology infusion within educator preparation.

Limitations

Q methodology allows for a research approach to gather perspectives across a variety of populations. We reviewed analytics provided by EQ Web Sort (Banasick, 2022) and eliminated sorts based on minimal time spent on sorting and incomplete qualitative responses. A subsequent manuscript will include a full analysis of each factor. Although the researchers discussed procedures for data collection, application in multiple contexts (in-class vs. other settings) was not always consistent. Some data were collected during regularly-scheduled class sessions, and some data were collected during out-of-class time. For example, participants could use online software to individually sort the items, and at another institution, TCs sometimes worked in small groups to submit a "collaborative" Q sort. Researchers actively teaching classes and/or researchers whose data collection appeared to have the active support of program administrators were able to recruit volunteers more readily. No students were "required" to submit a Q sort, and the participants completed them in different settings. Recruitment of participants took place online at some institutions and in person at others. Additional analysis could explore sorts completed by small groups of TCs rather than by individuals and examination of the data could include analysis by EPP, or content area program.

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Appendix
List of Candidate Q Statements

1. Technology allows PK12 students to collaboratively explore real-world issues and problems, develop ideas and theories, and pursue answers and solutions.
2. Technology allows PK12 students to understand and communicate complex ideas by creating or using a variety of digital objects such as visualizations, and models or simulations.
3. Technology can support PK12 student agency and voice in representing personal or community knowledge and experiences.
4. Technology can provide greater access to information and diverse viewpoints.
5. Technology-infused teaching methods are more effective than traditional instruction.
6. My teacher education program has coursework that requires teacher candidates to engage in multiple opportunities to practice integrating technology for teaching and learning.
7. My teacher education program provides opportunities for discussion, reflection, and feedback on ways to use technology for teaching and learning.
8. My teacher education program has an assessment structure in place to ensure that teacher candidates can implement technology effectively in support of PK12 learning.
9. My teacher education courses and field experiences demonstrate a shared vision of how digital technology should be integrated into instructional practices.
10. My teacher education program introduced frameworks for technology integration (e.g., TPACK, SAMR, Triple E).
11. My teacher education program has a curriculum designed to help candidates meet the International Society for Technology in Education (ISTE) Standards for Educators.
12. My teacher education program focuses on creating, producing, and problem-solving with technology.
13. Technology use for teaching and learning is expected and supported in my coursework and school-based experiences.
14. My teacher education program affirms the importance of equitable access to technology for PK12 learners.
15. My teacher education program provides access to technology resources for practice and use of technology in practicum and student teaching experiences.
16. Teacher education instructors model how to evaluate the benefits of content-specific technologies to support student learning.
17. Teacher education instructors model differentiation using assistive technologies to maximize learning for individual student needs.
18. Teacher education instructors model online and blended learning methods and strategies for PK12 learning environments.
19. Teacher education instructors model basic tech troubleshooting skills during teaching.
20. Teacher education instructors model technology use to include culturally relevant teaching.
21. Teacher education instructors are comfortable modeling technologies for teaching and learning.
22. Teacher education instructors facilitate candidate opportunities to practice teaching with technology.

23. Teacher education instructors provide candidates opportunities to create learning activities using technology to differentiate instruction for PK12 students.
24. Teacher education instructors provide opportunities for candidates to practice teaching online and/or in blended/hybrid learning environments.
25. Teacher education instructors provide candidates opportunities to use appropriate technology for assessment (e.g., portfolios, online quizzes, digital stories).
26. Teacher education instructors provide opportunities for candidates to create PK12 tech-supported learning activities to collaborate across a variety of backgrounds and cultures.
27. Teacher education instructors provide opportunities for candidates to design lessons following legal, ethical, and socially-responsible uses of technology.
28. Teacher education instructors support continued professional development of candidates to support technology integration.
29. Teacher education instructors support candidates in becoming advocates for using technology to enhance teaching and learning.
30. Teacher education instructors provide opportunities for candidates to analyze, create, curate, and evaluate digital resources.
31. Teacher education instructors provide opportunities to use technology to develop authentic learning activities for PK12 students to maximize active and deep learning.
32. Teacher education instructors provide candidates with explicit evaluation criteria for technology integration in assignments and field experiences.
33. My teacher education program has university supervisors who are knowledgeable about how to meaningfully integrate technology to enhance PK12 student learning.
34. My teacher education program has university supervisors who support candidates as they practice integrating technology for teaching and learning.
35. My teacher education program and my field placement encourage innovative methods to integrate technology in teaching and learning.
36. My teacher education program and my field placement are similar in terms of the types of resources available, including up-to-date hardware and software.
37. My teacher education program has school-based cooperating/mentor teachers who are knowledgeable about how to meaningfully integrate technology to enhance PK12 student learning.
38. My lessons integrate technology to support critical thinking and knowledge construction.
39. I can match content with effective technology (e.g., virtual manipulatives for math, digital stories for language arts and social studies).
40. The PK12 lessons I develop have students use technology to create original works (e.g., e-books, digital models, stories, videos).
41. My teacher education program has empowered me to feel prepared to teach with technology in the classroom.
42. Teacher education instructors give me sustained encouragement in my technology integration efforts.
43. My teacher education instructors celebrate my learning related to technology integration.

FROM CARNIVAL GAMES TO PLASTIC FILTERS: PREPARING ELEMENTARY PRESERVICE TEACHERS TO TEACH ENGINEERING

Jennifer Kidd
Old Dominion University, USA
jkidd@odu.edu

Pilar Pazos
Old Dominion University, USA

Kristie Gutierrez
Old Dominion University, USA

Danielle Rhemer
Old Dominion University, USA

Stacie Ringleb
Old Dominion University, USA

Krishna Kaipa
Old Dominion University, USA

Isaac Kumi
Old Dominion University, USA

Orlando Ayala
Old Dominion University, USA

Francisco Cima
Old Dominion University, USA

Abstract. Preservice teachers (PSTs) in an educational foundations course were tasked with leading elementary students in an engineering design challenge. Two instructional models were tested to explore different approaches for developing PSTs' competence in engineering education. In the first model, PSTs collaborated with undergraduate engineering students in cross-disciplinary teams to develop engineering lessons based on a carnival-themed design challenge. In the second model, PSTs worked in education student-only teams to teach a professionally prepared engineering lesson focused on designing plastic filters. PSTs' knowledge of engineering and engineering pedagogy were compared across the two semesters using an exploratory approach. Both groups demonstrated increases in engineering knowledge and engineering pedagogical knowledge. Item-level differences suggest unique benefits to each approach, providing insight for teacher educators designing interventions to prepare PSTs to integrate engineering into elementary education.

Keywords. P-12 Engineering, Elementary Engineering, Engineering Design Process, Engineering Pedagogical Content Knowledge, Preservice Teacher Preparation

Introduction

Research indicates that engaging elementary students in engineering can increase their technological literacy, which our society increasingly depends on to solve major societal and environmental challenges (Lachapelle & Cunningham, 2014; NGSS, 2013). When children craft a prototype as a solution to an engineering design challenge, they are engaging in making (Marshall & Harron, 2018; Rodriguez et al., 2018), a practice that involves "creatively designing and building material objects for both playful and useful ends" (Martin, 2015, p. 1). Making and engineering offer students agency and cultivate 21st-century skills, such as creativity, collaboration, and problem solving (Taylor, 2016), and have shown benefits in student engagement, self-efficacy, and interest in STEM (Papavlasopoulou et al., 2017).

Recent curricular efforts call for children to be introduced to engineering at an early age (NGSS, 2013). However, current literature highlights that few elementary preservice teachers (PSTs) are exposed to engineering as part of their PreK-12 schooling or professional teacher preparation (Hammack & Ivey, 2017). As a result, elementary teachers often feel unprepared to integrate engineering into their instruction (Rose et al., 2017). Thus, teacher preparation programs must develop PSTs' knowledge of engineering practices and pedagogy, so teachers can effectively integrate engineering into their future instruction.

PSTs in an educational foundations course at a mid-Atlantic university were introduced to engineering and tasked with leading elementary students in an engineering design challenge. Two instructional models were tested to explore different strategies for helping PSTs develop competence in engineering education. In the Carnival model, which took place in Spring 2022, PSTs collaborated with undergraduate engineering students (UESs) to develop carnival-themed design challenge lessons. In the Filter model, which occurred in Fall 2022, PSTs worked with their PST classmates to teach a professionally prepared engineering lesson focused on designing plastic filters. PSTs' knowledge of engineering and engineering pedagogy were compared across the two semesters. The goal was to explore the influence of the two models on PSTs' knowledge related to teaching engineering and to provide insight into approaches teacher educators can use to prepare PSTs to integrate engineering into elementary education. The current study examines the changes in PSTs' knowledge of engineering practices and pedagogy following lesson preparation and implementation with elementary students. Specifically, it asks:

1. What are the differences in PSTs' knowledge of engineering practices and knowledge of engineering pedagogy following two implementation models of teaching engineering lessons to elementary school students?
2. What do these differences suggest about the approaches for preparing teachers to integrate engineering into elementary education?

In response, this paper will provide an overview of the conceptual framework that informed the study along with a review of literature related to the development of PSTs' engineering-related

knowledge. It will then describe the two instructional models used across two different semesters to support the development of PSTs' engineering competence and explain the methods used to gather and analyze data. Next, it will share the results highlighting quantitative differences at the instrument and item level followed by a discussion and implications for the preparation of elementary PSTs to address the new engineering standards. Finally, the paper will conclude with plans for future research and a discussion of limitations of the study.

Conceptual Framework and Literature Review

Preparing teachers to integrate engineering requires the development of basic domain knowledge, relevant pedagogical knowledge, and the intersection of the two, often referred to as Pedagogical Content Knowledge (PCK) (Brophy et al., 2008; Shulman, 1986). PCK is the knowledge that connects a teacher's cognitive understanding of the subject matter content with the knowledge of how to teach that content effectively (Shulman, 1986). In the case of teaching engineering at the elementary level, there is agreement that the relevant content knowledge does not typically involve mastery of engineering facts, concepts, or theory, but it should focus on the hands-on application of the engineering design process along with a general understanding of the discipline and its practice (Cunningham & Carlsen, 2014; LaChapelle & Cunningham, 2014; Pazos et al., 2023). Shulman's model has been expanded to include intersections with domain-specific knowledge and broader pedagogical knowledge, such as the ability to use educational technology to enhance teaching and learning via Technological Pedagogical Content Knowledge (Mishra & Koehler, 2006). Engineering Pedagogical Content Knowledge (EPCK) then refers to a teacher's knowledge of pedagogical methods for supporting student engagement in the engineering design process. Teachers must understand how to guide students through this iterative series of steps that includes defining a problem; brainstorming, planning, and creating a solution to the problem; testing the solution and making improvements based on the results; and sharing findings with others (Lachapelle & Cunningham, 2014). EPCK furthermore calls for an understanding of how to identify developmentally-appropriate engineering design challenges tied to course content and to support students in engineering practices, such as the ability to work in teams and persevere through failure (Cunningham & Carlsen, 2014).

Literature on engineering pedagogical content knowledge is limited (Love & Hughes, 2022); however, related literature does suggest that there is a "strong connection between preparation experiences and educators' pedagogical content knowledge" (p. 5). Martin and Ritz (2014) identified PCK as a high-priority area of engineering educational research. Teacher preparation programs should concentrate both on the infusion of engineering content knowledge and engineering pedagogical knowledge, and on providing a greater number of "significant preparation experiences" (Love & Hughes, 2022, p. 16) to increase teachers' proficiencies in teaching engineering content and practices. This aligns with work by Sun and Strobel (2014), who found that teaching engineering in school settings was essential for teachers to construct their EPCK. Several studies have found that developing and teaching design-based engineering lessons improved PSTs' knowledge of engineering practices (Cima et al., 2022; Fogg-Rogers et al., 2017; Gutierrez et al., 2022; Lewis et al., 2021).

Providing PSTs with practical experience teaching engineering encourages them to take risks and "learn through experiencing the discomfort of being less certain about what is (or might

be) happening" (Nilsson & Loughran, 2012, p. 719). Teacher preparation programs play an important role in challenging PSTs to engage in authentic pedagogical tasks (e.g., lesson planning, direct instruction), particularly in content areas where they may not be as comfortable or familiar (i.e., engineering knowledge and practices). The current study examines the changes in PSTs' knowledge of engineering practices and pedagogy following lesson preparation and implementation with elementary students as part of the first course in a teacher preparation program.

Methods

Two models of an engineering education intervention were implemented over the course of two semesters as part of an introductory course for preservice teachers. In both models, the PSTs prepared for and taught an engineering lesson with an engineering design challenge to fourth-grade students; however, the models differed in team composition, engineering design challenge, and lesson preparation activities. The study was approved by the University's institutional review board, and participants signed media release forms.

In the Carnival model, which occurred in Spring 2022, PSTs and first-year engineering students collaborated in cross-disciplinary teams to lead fourth graders in carnival-related engineering design challenges. Team evaluation software, the Comprehensive Assessment of Team Member Effectiveness (CATME) (Loughry et al., 2014), was used to place education and engineering students with compatible schedules and heterogeneous GPAs into teams of four to five. Although the engineering and education students were enrolled in separate courses, the courses were held concurrently, and the two instructors brought their classes together for three collaborative class sessions. During those sessions, the teams completed an engineering design challenge, engaged as students in the specific design challenge they planned to teach, and practiced teaching their lesson to a group of peers. Teams met outside class three times to create a team charter, draft their lesson, and finalize their lesson following feedback.

The carnival theme was selected because COVID-19 restrictions were still in place, and the lessons would be taught outdoors. The teams were given the choice of three engineering design challenges that simulated outdoor carnival attractions: a claw, a paddle-powered boat, or a kicking machine. The instructors modified existing instructional materials to create a one-page guide for each challenge with suggested supplies, vocabulary, and tips. The engineering students were tasked with designing and building a "testing station," which the children would use to test their claw, boat, or kicking machine (Figure 1). Following this construction, teams moved through their design challenge and piloted their testing stations during a collaborative class session. After this initial test, teams redesigned their testing stations as needed and drafted a lesson plan to lead a group of fourth graders through their chosen challenge. The lesson plan required a number of elements, including: learning targets; safety considerations; lesson logistics/roles; an ice-breaker to learn the children's names; an introduction to engineering, the engineering design process, and their topic; guiding questions to lead the children through each step of the engineering design process; and a written review quiz aligned with their learning targets. To rehearse, each team taught their lesson to a group of peers and received feedback on their performance and lesson plan. After reviewing their feedback and making final revisions, 14 cross-disciplinary teams delivered 75-minute lessons at two participating schools.

Figure 1

Carnival-Themed Engineering Design Challenges Incorporating Testing Stations Designed by First-Year Engineering Students during Spring 2022

Paddle-powered boats *Mechanical claw* *Kicking machine*

In the Filter model, implemented in Fall 2022, PSTs collaborated with their education classmates to teach a plastic filter design lesson for fourth graders visiting the university campus. Similar to the Carnival model, the teams were formed with CATME, and PSTs prepared through both in-class and out-of-class meetings. However, unlike the Carnival model, no engineering students were involved. Besides the difference in team composition, other major differences between the models included the engineering design challenge and lesson preparation.

The filter lesson was adapted from a Youth Engineering Solutions (YES) unit where students "consider the effects of plastics on the marine ecosystem and community as they engineer filters to reduce plastic waste entering the ocean" (YES, 2023, para. 1). The lesson was selected because it closely aligns with the fourth grade Virginia Science Standards of Learning and because it was determined that the PSTs, who were in their first education course, would likely be more successful teaching on their own with a pre-made lesson rather than trying to develop a lesson based only on a brief outline (as was done in the Carnival model). The original YES unit spanned seven lessons and thus had to be condensed to fit a shorter time frame. The course instructor reduced it to two lessons: a pre-lesson that she taught to the fourth graders a day ahead of the main lesson to introduce the effects of plastic pollution on ocean ecosystems and the 105-minute lesson taught by the PSTs that engaged the fourth-grade students in the engineering design process to design, build, and test a filter that would catch plastics pollutants as they exited a model river and flowed into a model bay (Figure 2).

Figure 2

In Fall 2022, Fourth Graders Designed Plastic Filters Using a Lesson Adapted from Youth Engineering Solutions (YES)

Children testing their filter in a model bay

A PST utilizing the instructor-made slideshow

While the carnival lessons were delivered outside to accommodate pandemic-related restrictions, the filter lessons were taught in the more formal environment of a university classroom. Furthermore, the filter lesson PSTs utilized an instructor-created multimedia slideshow to guide students through the lesson. PSTs customized the slideshow during their preparation process, adding designated elements, including: a strategy to learn the children's names, learning targets, safety rules, and multiple-choice review questions. The slideshow also facilitated logistical planning, such as the distribution of supplies, and the designation of team member roles, indicating who would present each slide. Consequently, the filter lesson preparation focused mainly on customizing a prepared lesson and distributing the teaching workload, rather than on developing content for an original lesson plan, as was the case for the carnival lesson PSTs.

The researchers used quantitative analysis to compare PSTs' engineering knowledge and engineering pedagogical content knowledge between and within the two models using six measures. There were two types of instruments: self-report surveys that assessed PSTs' *perceptions* of their knowledge and multiple-choice tests that *directly* assessed PSTs' engineering-related knowledge. Subscales from a previously validated survey instrument (Pazos et al., 2023) were used to assess PSTs' perceptions of their knowledge related to (a) teaching, *Pedagogical Content Knowledge (PCK)*; (b) teaching engineering, *Engineering Pedagogical Content Knowledge (EPCK)*; and (c) engineering practices, *Knowledge of Engineering Practices (KEP)*. The subscales utilized a five-point Likert scale (1=strongly disagree, 5=strongly agree) and contained seven, seven, and nine items, respectively. Three instruments were used to directly assess PSTs' knowledge related to engineering and teaching engineering. PSTs' knowledge of what engineers do during the design process, or *Design Process Knowledge (DPK)*, was measured using 24 multiple-choice questions adapted for elementary school teachers (Nadelson, 2015). The authors developed a 15-item multiple-choice *Assessment of Engineering Knowledge (AEK)* to align with three knowledge-based objectives of the project: define engineering and name several subfields, describe the EDP, and explain basic math and science concepts connected to common engineering design problems. Finally, the authors developed a six-item multiple-choice *Engineering Pedagogical Knowledge Test* (EPKT) to align with key features of engineering instruction, including engaging students in the EDP, facilitating student inquiry, and

developing appropriate design challenges. In summary, three measures evaluated PSTs' knowledge of engineering and three evaluated PSTs' knowledge of pedagogy. Likewise, three measures assessed PSTs' *perceptions* of their knowledge and three measures *directly* assessed their knowledge.

Results

Two inferential statistical analyses were conducted, the first looking at changes over time within each of the two models and the second comparing the two models across all measures. The first analysis addressed the question of whether changes were observed in the variables of interest within each model. A paired t-test was used for each measure to determine whether the means of the pretest and posttest scores were statistically different within each group of PSTs. Differences were determined based on a significance level of p-value < 0.05. The second analysis utilized Analysis of Covariance (ANCOVA) to look for differences between the Carnival and Filter models across each measure. The pretest scores were used as control variables to account for potential pre-existing differences. While standard parametric analyses were used, it is important to note that the sample sizes were small, and the data did not meet all assumptions (e.g., normality) for this type of analysis. Consequently, results should be interpreted cautiously.

There was a significant increase between the pre- and post-values for all three *self-assessment* measures for both the Carnival and Filter groups, indicating an overall gain in PSTs' assessment of their understanding. Both groups self-reported an increase in knowledge after the completion of the project. For the *direct knowledge tests*, there were significant increases in *Design Process Knowledge* (DPK) for both groups and a significant increase on the *Engineering Pedagogical Knowledge Test* (EPKT) for the Filter group. Results are summarized in Table 1 for PSTs' self-assessment surveys and Table 2 for the multiple-choice knowledge tests. There were no significant differences between the two groups on any of the measures when controlling for pretest values, suggesting similar levels of overall understanding of engineering knowledge and engineering pedagogical knowledge in both groups. Between-group results are summarized in Table 3.

Table 1

Paired T-Test Results for PSTs' Perceived Knowledge

		Carnival model (Spring 2022)					**Filter model (Fall 2022)**				
		n			t-test		n			t-test	
			Mean	SD	t	p-value		Mean	SD	t	p-value
PCK	pretest	16	3.55	0.79	4.79	0.00*	10	3.70	0.43	3.16	0.01*
	posttest		4.42	0.55				4.40	0.59		
EPCK	pretest	16	2.74	1.10	5.56	0.00*	10	2.30	0.93	5.28	0.00*
	posttest		4.42	0.55				4.46	0.60		
KEP	pretest	16	3.15	1.11	5.21	0.00*	10	3.16	0.80	4.71	0.00*
	posttest		4.47	0.48				4.46	0.47		

Notes. ns=no significant differences between groups; *p-value < 0.05. PCK = Pedagogical Content Knowledge; EPCK = Engineering Pedagogical Content Knowledge; KEP = Knowledge of Engineering Practices.

Table 2

Paired T-Test Results for the Multiple-Choice Knowledge Tests

		Carnival model (Spring 2022)					Filter model (Fall 2022)				
					t-test					t-test	
		n	Mean	SD	t	p-value	n	Mean	SD	t	p-value
DPK	pretest	14	8.64	5.34	4.90	0.00*	8	9.62	4.14	2.61	0.03*
	posttest		13.3	3.05				14.2	4.40		
AEK	pretest	14	9.43	5.03	1.09	0.29	9	10.4	3.97	1.73	0.12
	posttest		10.3	3.36				12.0	1.66		
EPKT	pretest	17	2.76	1.44	0.39	ns	9	2.44	1.13	3.83	0.00*
	posttest		2.94	1.71				3.89	1.36		

Notes. ns=no significant differences between groups; *p-value < 0.05. DPK = Design Process Knowledge; AEK = Assessment of Engineering Knowledge; EPKT = Engineering Pedagogical Knowledge Test

Table 3

ANCOVA Results by Variable

	Carnival model (Spring 2022)			Filter model (Fall 2022)			ANCOVA test	
	n	Adj. Mean	SE	n	Adj. Mean	SE	F	p-value
PCK	16	4.44	0.13	10	4.37	0.17	0.085	0.77
EPCK	16	4.43	0.14	10	4.44	0.18	0.002	0.96
KEP	16	4.47	0.11	10	4.46	0.14	0.009	0.92
DPK	14	13.4	0.80	8	14.0	1.07	0.172	0.68
AEK	14	10.5	0.44	9	11.7	0.55	2.84	0.10
EPKT	17	2.89	0.36	9	3.99	0.50	3.067	0.09

Notes. PCK pre grand mean = 3.61; EPCK pre grand mean= 2.57; KEA pre grand mean= 3.15; DPK pre grand mean= 9; AEK pre grand mean = 9.83; EPKT pre grand mean= 2.65.

Discussion and Exploratory Item-Level Analysis

The purpose of the study was to compare two models for preparing PSTs to teach elementary-level engineering with the intention of offering insights to teacher educators engaged in such work. Accordingly, individual items were examined to provide a granular and nuanced look at PSTs' understanding of engineering and engineering pedagogy. As such, pretest and posttest means on individual items were reviewed to look for topics where:

a. Both groups scored high (> 90% correct or > 4.0) or showed strong gains (> 25% or +1.0);
b. Both groups scored low (< 60% or < 3.0) or showed decreases (> 20% or -1.0);
c. Notable differences existed in the groups' performance (> 25% in posttest means or > 25% difference in gain scores) that may suggest different levels of understanding.

The next section includes a discussion of the inferential test results reported above combined with an exploratory item-level analysis to explore connections between the PSTs' performance on the measures and the implementation models. The PSTs' performance is

discussed for each of the two variables: engineering knowledge and engineering pedagogical knowledge. Within these discussions, the PSTs' holistic performance on the measures is discussed first, followed by the two groups' performance on selected individual items.

Engineering Knowledge

Three instruments were used to assess PSTs' knowledge of engineering. One focused on PSTs' self-reported assessment of their *Knowledge of Engineering Practices* (KEP). The other two were direct tests of engineering knowledge, one that assessed *Design Process Knowledge* (DPK) and one that focused on knowledge related to the objectives of the project (*Assessment of Engineering Knowledge*) (AEK). There were no significant differences between the groups in PSTs' perceptions of their *Knowledge of Engineering Practices (KEP)*, but there were significant pre-post differences within each condition. Both groups showed increases (0.5 - 1.8 points), suggesting that the PSTs believed they learned engineering content knowledge over the course of the project. With the exception of familiarity with different fields of engineering, which had a mean just below 4.0, posttest means were high (most 4.5 and above), indicating that the PSTs believed they had a strong understanding of engineering practices at the end of the project. The highest means for both groups were on items related to constraints and brainstorming, two concepts covered extensively in the implementations.

PSTs from both models showed increases in *Design Process Knowledge* (DPK), averaging about four more questions correct on the posttest, suggesting that PSTs' actual engineering content knowledge increased along with their perceptions of their knowledge. While the within-group differences were significant, there were no significant differences between the groups' overall scores. However, group differences on individual items across the two engineering knowledge tests correspond to differences in the implementation models. First, based on their answers to related test items, Filter lesson PSTs were more likely than their Carnival lesson peers to see the engineering design process as a linear, step-by-step process, similar to a recipe, as opposed to cyclical and iterative. This divergence in PSTs' understanding of the engineering design process could result from differences in the nature and structure of the engineering design challenges implemented in each semester. The Filter lesson, adapted from YES, included a poster of the engineering design process (EDP) with an arrow that PSTs moved to indicate the phase of the EDP currently being discussed. Although the poster shows the EDP as circular, the methodical moving of the arrow from one phase to the next may have reinforced the notion of a linear pathway. Second, Filter lesson PSTs were more likely to correctly answer questions that recognized engineers' responsibility to focus on client needs at the start of and all throughout a project. This responsibility was demonstrated in the Filter lesson when the children role-played various stakeholders concerned about plastic pollution, but this responsibility was not discussed in the Carnival lesson. Interestingly, both groups scored low on a related question, *At the beginning of a project, excellent designers devote most time to defining the problem*, suggesting that PSTs may need more help understanding what problem definition entails and why it is important. Finally, some item-level differences between groups related to specific science concepts. Carnival PSTs performed better than their Filter lesson peers on items assessing their understanding of thrust and potential energy, concepts connected to their carnival-themed challenges. There was no discussion of these concepts in the Filter lessons. This introduces the idea that engineering design challenges could be purposefully selected to help

reinforce specific science concepts, perhaps to help prepare PSTs for Praxis or similar licensure exams.

The item-level analysis revealed strong increases in engineering content knowledge across both groups on specific topics. PST responses indicated gains in their understanding of what constitutes an engineering design task, the iterative nature of the engineering design process, and the presence of multiple valid solutions to engineering problems. This suggests both models were helpful in enhancing PSTs' understanding in these areas. Low scores across both groups highlight areas where PSTs lacked understanding. Neither group of PSTs understood that manufacturing a final product is not necessarily part of the design process, nor did they realize that mechanical components are typically tested to failure. This suggests neither model contributed meaningfully to PSTs' understanding of these engineering practices. More than 50% failed to recognize that an engineer's next step after meeting design criteria is communicating results to stakeholders. This result was somewhat surprising, especially for the Filter group, as their lesson specifically included a phase for sharing results. However, this phase came at the end of the lesson and may have been rushed through or skipped. PSTs' weak performance on another item may also have been connected to time constraints within the lessons. Rather than responding that a student should draw a plan of their idea after identifying promising materials, PSTs in both groups were likelier to say the student should move directly to building and testing their design. In the execution of their lessons with elementary students – often in response to students' excitement to get started and pressure to finish the lesson in the allotted time – many teams moved quickly through the planning phase of the EDP. This tendency for PSTs to have students move quickly from brainstorming to creating, rather than carefully planning out a design based on their understanding of science concepts, such as material properties, could also help explain why more PSTs indicated that engineering was largely a process of trial and error at the posttest than they did at the pretest. If PSTs do not help students connect their design decisions to underlying STEM principles, either initially or during the redesign phase, engineering can seem like a process based mainly on trial and error. This undergirds the importance of designing engineering lessons with adequate time for children to explore materials and engage in the plan and improve phases of the EDP. Elementary students, as well as PSTs, need time to see how scientific principles, such as material properties, affect the success of their designs and how they can apply newfound knowledge to make better design decisions that result in more successful solutions.

Pedagogical and Engineering Pedagogical Knowledge

Three instruments were used to assess PSTs' knowledge of engineering pedagogy. Two were self-report measures: one focused on pedagogy broadly (PCK), the other focused on engineering-specific pedagogy (EPCK). The third instrument was a multiple-choice test of engineering-specific pedagogy (EPKT). There were no differences between the groups in PSTs' perceptions of their Pedagogical Content Knowledge (PCK). There were, however, statistically significant within-group differences in both models, with high posttest means (> 4.0) suggesting that PSTs felt confident in their general pedagogical knowledge at the end of the project. Some of the highest gains (~1.2 points) were seen in the PCK subscale question *I know specific strategies to guide rather than lecture students*, indicating that PSTs gained familiarity with active learning strategies critical for teaching engineering.

There were no significant differences between the groups in PSTs' perceptions of their engineering-specific pedagogical content knowledge (EPCK), but there were significant and quite large (1.4-2.5 points) within-group differences in each model, suggesting the PSTs in both groups believed they learned a great deal about teaching engineering during the project, like how to introduce the engineering design process to students. Furthermore, the gain in the engineering pedagogical content knowledge (EPCK) subscale was the most substantial of all measured outcomes, with high posttest means (>4.25), indicating that the implementation had the largest influence on PSTs' perceptions of their knowledge about teaching engineering and that PSTs believed they had a strong understanding of engineering pedagogical content knowledge (EPCK) at the project's end.

The direct test of engineering pedagogical knowledge (EPKT) painted a fuzzier picture. There were significant within-group differences for the Filter lesson PSTs but not for the Carnival lesson PSTs; however, the difference in mean scores between the two groups was not significant. This suggests that the Filter lesson PSTs gained knowledge of how to teach engineering, while the influence of the project on the Carnival lesson PSTs is less clear. An examination of individual items highlights a concern for both groups. Both Filter and Carnival PSTs had trouble recognizing that a step-by-step set of instructions from a website would not be a good example of an engineering design challenge for children. Presumably, several PSTs were unaware that the prescribed activity did not require students to make design choices and, therefore, would not constitute a design problem. This suggests PSTs may need to engage in discussions of what constitutes engineering.

A trend that surfaced in the content knowledge test results was also observed in the pedagogy test results. Filter lesson PSTs did better than their Carnival lesson counterparts on questions related to the importance of interacting with clients during the design process, suggesting they may have gained more knowledge on the responsibility engineers have to meet clients' needs and how to integrate that responsibility into the design process. As discussed above, the Filter lesson included an activity requiring students to represent stakeholders, which drew attention to client needs before students even began developing their designs. This activity may have served as a model, demonstrating how consideration of client needs can be incorporated into the design process.

The differences in the PSTs' performance may be connected to the implementation model they experienced, especially the preparation activities they completed and the engineering design challenge that formed the backbone of the lesson they taught. There were several key distinctions that likely influenced the outcomes. First of all, Filter lesson PSTs followed a prepared, highly structured engineering lesson that led fourth graders through well-articulated phases of the engineering design process, including a materials testing phase and a prolonged problem definition phase. The prepared lesson, based on materials developed by Youth Engineering Solutions (YES), may have served as a model of effective pedagogical strategies, and thereby contributed to the Filter lesson PSTs' increase in engineering pedagogical knowledge. In contrast, Carnival lesson PSTs collaborated with their engineering partners to design their own lessons using only a brief handout provided by their instructor that outlined their selected design challenge. Consequently, the carnival lessons were less elaborate with fewer activities within each EDP phase. Furthermore, they were taught outside, and as they were intended to simulate

carnival games, they tended to be less regimented. The contextual differences in the two models likely influenced the PSTs' understanding of the design process and how to guide students through it. The highly structured Filter lesson, in which PSTs moved an arrow on a poster depicting the engineering design process to show the phase in which the students were currently engaged, may have given PSTs the impression that engineering tends to (and should) proceed in a linear, step-by-step fashion, whereas the more loosely structured Carnival lessons may have presented a more flexible example of the engineering design process. These experiences may help explain why the Carnival lesson PSTs were more likely than their Filter lesson peers to correctly disagree with the following question from the DPK assessment: *The process of solving a design problem is much like that of following a recipe.* Another difference in preparation, may also have contributed to this result. The Carnival lesson PSTs assisted their engineering teammates in designing the testing stations the fourth graders used to evaluate their prototypes (Figure 1). This participation involved them in an authentic, iterative engineering task. As they were also involved in the design of the lesson they taught, the Carnival PSTs were engaged in two interactive design activities beyond the design challenge included in their lesson. Participating alongside the engineering students as they iterated on both the design of the lesson and testing stations may have also reinforced the Carnival PSTs' notion of engineering as an organic process that occurs over multiple trials.

The topics of the engineering design challenges were also an important variation. The carnival-themed challenges focused on physical science principles (e.g., utilizing potential energy from a twisted rubber band) rather than a societal issue (e.g., plastic pollutants in waterways). As the Carnival lesson PSTs had to develop their own lesson materials, including demonstrations and explanations to help students apply relevant concepts in their designs, they likely invested substantial time reviewing and rehearsing related science content. In contrast, the Filter lesson was prepared by the course instructor and only required the elementary students to understand how potential filter building materials interacted with water (e.g. absorb, repel), something they tested at the start of the lesson. Accordingly, the Filter lesson PSTs were unlikely to need to review science concepts in order to successfully deliver their lesson. Furthermore, the physical science focus of the Carnival lessons concentrated the elementary students' energy on the mechanical performance of their prototypes, whereas the students completing the filter lessons were directed to consider the community impacts resulting from the performance of their designs. Consequently, the Filter lessons PSTs prompted the students to consider how the design and success of their filter prototypes would affect multiple stakeholders (e.g. marine animals, boaters, swimmers). Each engineering design challenge thus emphasized different engineering practices, such as applying scientific knowledge to problem-solving, considering problems in context, and assessing the implications of solutions (Cunningham & Carlsen, 2014). The Filter lesson PSTs' inclination to suggest students check in with a client before prototyping reflects the focus of their design challenge on the practice of considering problems in context enacted when the students role-played various community members prior to designing their solutions. In contrast, the Carnival lesson did not specify a client beyond the participating students and thus did not emphasize a social context for their problem or responsibility to stakeholders. However, the Carnival lesson PSTs did act as stakeholders in the design of the testing stations used in their lessons, providing feedback in anticipation of the fourth graders' ability to utilize the devices to assess their prototypes, but they may not have seen themselves as clients in this design process.

Had the instructors emphasized this relationship, the Carnival PSTs may have better understood the client's role in the design process.

Implications

Preparing PSTs to teach engineering is tricky because it requires the development of both content knowledge and pedagogical knowledge. The gains in PSTs' design process knowledge and perceived knowledge of engineering practices, on top of gains in perceived pedagogical knowledge, suggest that teaching engineering lessons to elementary students can address both needs simultaneously. PSTs learned about engineering as they prepared for and taught engineering lessons. Specifically, PSTs demonstrated an increased understanding of the engineering design process, what constitutes a design task, and the presence of multiple valid solutions to engineering problems. Despite these knowledge gains, the results indicate a few areas where the participating PSTs fell short in their understanding of engineering, even within these areas of improvement, and thus reveal opportunities for the instructional models to be improved. Moving forward, the authors suggest that teacher educators who are engaged in engineering education highlight key ideas to properly frame engineering. First, we recommend engaging PSTs in a discussion of what constitutes engineering to reinforce the notion that design challenges require students to make design choices and that activities that provide a prescribed set of step-by-step instructions would not qualify as engineering. Next, we encourage teacher educators to be mindful of the need to present the EDP as an iterative process that involves stakeholders at multiple points to ensure that engineers' responsibility to their clients and society at large is abundantly clear. Introducing a design challenge in its social context, discussing the impact of the problem and potential solutions on multiple parties, can also help PSTs understand why engineers devote significant time to problem definition as they begin a project. Finally, to represent engineering as a problem-solving process that applies math and science concepts and differentiate it from a simple process of repeated trial and error, the authors emphasize the importance of designating adequate time for engineering lessons so students can plan, evaluate, and redesign solutions based on related STEM principles. Providing ample time can also ensure students share their results with others, an important reflection and communication step that is easily skipped if time runs short.

This study has implications for teacher educators as they search for effective approaches to prepare PSTs to integrate engineering into elementary-level instruction. The increases in PSTs' perceptions of their knowledge of engineering and engineering pedagogy and the actual increases in PSTs' design process knowledge after the implementation suggest that having PSTs teach engineering lessons to elementary students is a promising strategy. Several instructional elements were common to both implementation models used in this study and may have contributed to the enhancement of PSTs' engineering-related knowledge. First, PSTs in both models taught lessons to elementary school children. While other approaches to preparing PSTs may engage them in engineering activities where they participate in engineering design challenges as students (e.g., Cunningham & Kelly, 2017; Sun & Strobel, 2014) or develop an engineering lesson plan for a hypothetical classroom (e.g., Maiorca & Mohr-Schroeder, 2020), these activities do not necessarily include interaction with elementary students. The PSTs in both the Carnival and Filter models interacted with real students, witnessing the students' reactions to their instruction and thereby gaining feedback on their teaching performance. This feedback may have enhanced

their understanding of pedagogy generally and engineering pedagogy specifically, by allowing the PSTs to see the effects of their instructional moves. Second, the PSTs in both models prepared for and delivered their engineering lessons in the context of a teaching team. This interaction with other college students provided additional resources and feedback for the PSTs to draw upon as they planned for and reflected upon the success of their lessons, likely contributing to their engineering knowledge and engineering pedagogical content knowledge. Teacher educators should consider providing opportunities for PSTs to collaboratively teach engineering lessons to elementary students. Such opportunities could be organized in the context of existing field placements or through novel activities like those described in this study.

As the comparison of the outcomes between the two instructional models did not produce statistically different results, it is less clear how such collaborative engineering teaching activities should be structured. There are advantages and disadvantages to the different approaches used in the two models related to team composition, the engineering design challenge on which the lessons were based, and the PSTs' lesson preparation activities. As the authors move forward in their preparation of PSTs for teaching engineering, they plan to continue researching PST-only teaching teams. While they acknowledge benefits from cross-disciplinary collaboration, more time and resources were required to support this model. PST-only teams may be more scalable, and the results of this study suggest they can produce similar PST outcomes. Teacher educators could consider the feasibility of either team-teaching model at their individual institutions, depending on their access to engineering collaborators and their goals for the teaching experience. PSTs who collaborate with engineering students may have additional opportunities to encounter the enactment of engineering practices as compared to PSTs who work in education student-only teams. At the same time, teacher educators may find it easier to plan for their students without having to consider the needs of student collaborators from another discipline. Looking ahead, the authors plan to utilize prepared lessons for novice PSTs who may not be ready to design their own lessons. These lessons have the added benefit of serving as models of effective engineering pedagogy. However, the authors will continue to assign seasoned PSTs (e.g., those enrolled in a science methods course that comes near the end of their program) to develop their own engineering lessons. More advanced PSTs can benefit from this challenge and from engaging in an interactive design activity. Teacher educators should consider the developmental level of their students and how much exposure they have had to engineering as they determine how involved PSTs should be in lesson development. Similarly, teacher educators can purposefully select engineering design challenges to reinforce science concepts on which their PSTs may need more practice.

Conclusion

Teacher educators are confronting a new reality where they must prepare elementary preservice teachers to integrate engineering into preK-6 instruction. Little research exists on how best to accomplish this. This study presents two different models for doing so, both of which include PSTs teaching engineering lessons to fourth graders. Self-report surveys and knowledge tests were used to examine the influence of the models on PSTs' knowledge of engineering and knowledge of engineering pedagogy. Results showed positive effects on PST knowledge and perceptions of knowledge for both models, suggesting that engaging PSTs in teaching engineering lessons to elementary students is a beneficial approach to preparing them to teach

engineering. An exploratory analysis comparing the responses of PSTs on individual items was done to provide additional insight into the two different approaches on PST learning. While these findings should be interpreted cautiously, they seem to suggest the different models may have reinforced different knowledge and understandings related to the engineering design process. PSTs who taught a highly structured and premade lesson on plastic filters were better able to answer questions about the engineering design process and more likely to recognize an engineer's responsibility to meet a client's needs but were also more vulnerable to the misconception that engineering is a linear, step-by-step process. In contrast, PSTs who worked alongside engineering students and contributed meaningfully to the development of the lesson they taught were more likely to recognize the iterative nature of the design process and were better able to answer questions related to underlying STEM concepts reflected in their design challenges. Further research on this project will include an analysis of PSTs' written reflections, which should add insight into the PSTs' perceptions of what they learned and how their interactions with their teammates, either education students or engineering students, influenced their learning.

Limitations

This study was limited by several factors. The primary limitation originates from the small sample size and thus, the quantitative analysis is best described as exploratory and should be interpreted cautiously. The small samples violated some assumptions for the parametric analyses conducted. To mitigate this concern, nonparametric tests were also conducted and yielded the same results regarding significance, adding validity to the findings. An additional limitation concerns instrumentation. While the survey that assessed PSTs' perceptions of their knowledge of engineering practices, pedagogical content knowledge, and engineering pedagogical content knowledge was validated, the three instruments used to directly assess PSTs' engineering-related knowledge have not yet been validated. Furthermore, the instruments were not designed to measure distinct constructs within the domains of engineering knowledge and engineering pedagogical knowledge. Accordingly, the results associated with the item-level analysis, should be interpreted judiciously, with interpretations related to model comparisons considered speculative. Finally, the study was conducted at one university and in the context of a project supported by NSF funding with education and engineering faculty involved in a multi-year collaboration. Similar studies in other university contexts may yield different results.

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Acknowledgements
This material is based upon work supported by the National Science Foundation under Grant No. #1908743. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

PERCEIVED IMPACT OF AN EDUCATIONAL TECHNOLOGY COURSE ON ALTERNATIVE CERTIFICATION STUDENTS' UNDERSTANDING OF ISTE STANDARDS AND FUTURE CLASSROOM

Nicole Mishnick
Tarleton State University, USA
mishnick@tarleton.edu

Emily McLemore
Tarleton State University, USA

Dana Wise
Tarleton State University, USA

Abstract. As the demand for qualified educators continues to rise and with the integration of technology in education becoming a priority, educator preparation programs are increasingly tasked with ensuring candidates graduate with the pedagogical knowledge and technology skills necessary to prepare students for the 21st Century. Additionally, alternative teacher certification, a pathway for individuals with non-educational backgrounds to become certified teachers, continue to gain traction as a means to address the growing teacher shortage. Many individuals entering alternative certification programs lack the pedagogy and technology skills necessary to lead a classroom. This study examines the impact of an educational technology course on alternative teaching certification students' understanding of the International Society for Technology in Education (ISTE) Standards and its impact on students' future classroom practices. A qualitative case study design was utilized, with students completing a pre-and post-course survey related to their understanding of the ISTE Standards. Findings indicate that the educational technology course significantly improved students' understanding of the ISTE Standards, with participants recognizing the standards as a framework for technology integration in the classroom.

Keywords. Alternative Teacher Education, Teacher Preparation, Technology Standards, Technology-Specific Courses, Educational Technology

Introduction and Study Context

The national focus on preparing educators to integrate technology into their classrooms is evident. In 2014, the Council for the Accreditation of Educator Preparation incorporated technology as an overarching theme in their standards (CAEP, 2013). The National Education Technology Plan (US Department of Education, 2017) calls for all students to be engaged and empowered through technology. The Office of Educational Technology recommends that educator preparation programs integrate technology standards into their curriculum to ensure teachers are equipped to integrate technology into their classrooms. In Texas, Educator Preparation Programs must align their curriculum with the International Society for Technology in Education (ISTE) Technology Standards for Educators and implement a digital literacy evaluation into their program (State Board of Educator Certification, 2019).

Educator preparation programs have responded to the state requirement in multiple ways. Some programs integrate the use of technology tools into content-specific instruction (Graham et al., 2009), with others creating courses focused on technology tools such as digital tools, content creation, and content curation tools (Hsu, 2012). Previous research has shown the impact of technology pedagogical content knowledge (TPACK) when technology has been integrated into content methods courses (Graham et al., 2009). Similarly, Hsu (2012) found that a technology-specific course benefited preservice teachers and increased their technology knowledge. However, previous studies focused on traditional educator programs and general technology knowledge. This study examines the impact of a technology-specific course in an alternative certification program and asked: *How did the educational technology course affect the development of alternative certification teachers' understanding of the ISTE Standards and impact their teaching?* To answer this question, researchers created a course focused on the ISTE Standards and their role in the classroom. Students' understanding of the ISTE Standards was measured pre- and post-course to gain insight into the course's impact, and the results will be reported.

Theoretical Framework

While both the ISTE Standards and the TPACK framework are valuable theoretical perspectives for discussions on technology and teaching, they approach technology integration in education from different perspectives (DeSantis, 2016). TPACK is widely used for teacher professional development, and in a 2022 meta-analysis study of teacher education interventions and TPACK, Ning et al. (2022) found that the longer the intervention and support of educators with technology integration, the better the technology integration within the classroom. Further, while TPACK is focused on what teachers “know,” the ISTE Standards for Educators are centered on what the teachers “do” (DeSantis, 2016).

In 1998, ISTE, a group of progressive K-12 and higher educator educators, released its first set of standards, known as the National Educational Technology Standards (NETS). In 2007, the NETS were evaluated and re-released as the ISTE Standards for students. The teacher and administrator standards were added in 2008 and 2009. Over the years, the ISTE Standards have

undergone several revisions in an attempt to keep pace with the rapid evolution of technology and the needs of the educational landscape (ISTE, 2024) The early versions focused on basic computer literacy and the integration of software applications, while the current versions emphasized digital citizenship, creativity, and the use of technology to facilitate personalized learning experiences. Currently, the ISTE standards serve as a framework for educators, leaders, and teachers to utilize technology to enhance student learning, have been adopted in all fifty US states and are available in nine languages. (ISTE, 2024).

While the ISTE Standards have been updated and revised on a regular basis, critiques of the standards have emerged. Scholars have raised concerns regarding the lack of transparency in the creation and revision of the standards, possible equity issues related to the implementation of the standards, and lack of formal assessment to measure their efficiency. Additionally, the ISTE Organization is a for profit organization which charges a fee for educators to become ISTE Certified. Therefore, they profit off of organizations and state's adopting the ISTE Standards (Cherner et al., 2021).

However, despite the concerns surrounding the ISTE Standards, they provided the appropriate framework for this research as they are mandated by the state and the participants in the course are working in the classroom and expected to use technology within their lessons. As alternative certification educators, these students are expected to use appropriate technology standards while learning to be effective educators. Moreover, the ITSE Standards "show educators learning alongside their students and educators leading others locally and globally" (Crompton, 2022, p. 31).

The professor taught this course through the lens of the ISTE Standards for Educational Leadership. Specifically, standard 3.3b that states: "Build the confidence and competency of educators to put the ISTE Student Standards and ISTE Educator Standards into practice" (*ISTE Standards: For Education Leaders* 2024). While all of the ISTE Standards for Educational Leadership are valuable and necessary for building strong educators, the choice to focus on standard 3.3b was tied to the knowledge that without self-efficacy in not only their pedagogical skills but educational technology skills, educators struggle to incorporate technology into their teaching with the fidelity needed for success (Rabbianty et all., 2024). A 2020 study on pre-service teachers' perception of technology competency found that more than half of the survey respondents felt that their credentialed teaching program did not give them opportunities to build competency in using technology in teaching (Kimm et al., 2020). Additionally, as the students in the class are currently working as teachers across PK-12, it is crucial to spend to focusing on building confidence and competency as foundational principles. A teacher's perception of a "digital - competent teacher" has the power to position the teacher for success, or failure, in the classroom (Çebi & Reisoğlu, 2022).

Literature Review

Alternative Certification Programs

Alternative teacher certification programs allow individuals with a bachelor's degree a non-traditional path to becoming a certified teacher. Individuals enrolled in these programs can

earn a wage as a classroom teacher while enrolled in the program and working towards their teaching certificate. Alternative programs have become increasingly popular in recent years in an attempt to address the growing demand for qualified educators. In Texas alone, in 2022, approximately 47% of initial standard teaching certificates were awarded to alternative preparation-certified teachers (Landa, 2023). Further, a third of all teachers in Texas gained their certification through an alternative program (Kwok & Cain, 2023). Within these programs, the inclusion of technology-infused courses has gained attention due to the evolving role of technology in education (Williams et al., 2023; Buss et al., 2018). Teachers prepared through alternative certification programs come from diverse backgrounds, and a targeted technology curriculum can positively impact teachers' self-efficacy in technology integration (Lythreatis et al., 2022).

Technology Integration in Curriculum

The US Department of Education (2024) defines the Digital Divide as an inequitable support of learning through the use of technology. Digital inequities can exist in both access to technology and implementation and integration of technology into learning activities. One key area of focus is the role of technology courses in bridging the Digital Divide among educators. As classrooms evolve to meet the demands of 21st-century learning, the integration of technology is crucial. Educators need guidance on effectively navigating and utilizing online resources, contributing to successfully implementing blended learning strategies (Howard, 2020). Without resources, teachers find themselves in the second-level Digital Divide, which refers to the difference in digital skills and digital usage (Lythreatis et al., 2022). Technology-infused courses model the necessary digital skills to navigate contemporary classrooms and support successful and productive classroom teachers (Powers et al., 2020; Williams et al., 2023).

Relationship Between Technology Training and Teaching

Further, studies have explored the correlation between teacher technology training and student achievement (Harris et al., 2016). While the relationship is complex and context-dependent, evidence suggests that teachers with strong technology skills can create more engaging lessons, potentially positively impacting student outcomes (Buss et al., 2018). Previous scholars established the impact of technology-specific courses on pre-service teachers' technology knowledge and instruction (Hsu, 2012). However, limited research on the impact of technology-specific courses on alternative certification programs exists. This study aims to fill that gap and examine the impact of the technology-specific course on alternative certification teachers' understanding of the ISTE Standards and its impact on teaching.

Methods

This study utilized a qualitative research methodology, specifically a case study design (Creswell, 2012), to answer its research question. A case study design is appropriate because they focus on a program or event (Stake, 1995). This study examines a specific course within an educational program, which the researchers see as a specific program.

Context

This study was conducted with students enrolled in an alternative teaching certification program at a four-year, mid-size university in Texas. To be enrolled in the program, students must be at least 18 years of age, hold a bachelor's degree, have an overall GPA of at least 2.75, and seek teaching certification in a content area supported by the university. Students choose this program because it allows them to earn their teaching certificate as well as graduate course credit. Once accepted into the program, students take courses related to classroom management, effective teaching, pedagogy, and literacy development. The course utilized for this study focused solely on educational technology in the classroom. This course is the only course students take in relation to technology, and it covers effective technology integration in the classroom and the ISTE standards. The three-credit course is offered asynchronously and facilitated by a professor with a Ph.D. in Leadership with a specialization in Education.

Participants

The authors recruited participants through the course upon approval from the institutional review board. Consistent with convenience sampling, participants were recruited from a single program and willingly agreed to participate in the study (Teddie & Tashakkori, 2019). Because this study examined the impact of a specific course, all students in it were invited to participate. All students completed the pre- and post-course surveys, which were administered using a Google form. However, only students who provided consent were part of the study. Consent to participate in the study was obtained by students providing the last four digits of their student ID. Initially, 16 students consented and completed the pre-survey. However, only six students completed consent for the post-survey. The decrease in students completing the post-course survey may have resulted from access issues when the survey was initially shared. The issue was rectified, but many students had already completed the course and did not log back in to complete the survey. Basic demographic information on students that completed the pre and post course survey are included in Table 1.

Table 1

Participant Demographics

	Pre-Course	Post-Course
	n	*n*
Gender		
Female	14	5
Male	2	1
Age		
21-30	9	3
31-40	3	2
41-50	4	1

Data Collection

The authors collected data in two phases. First, students who agreed to participate in the study completed a pre-course survey (Appendix A) to gather demographic information, gauge students initial understanding of the ISTE Standards, determine how students believe the ISTE Standards will impact their classroom, and understand students' initial thoughts regarding the course. During the final week of the course, students completed a post-course survey. The post-course survey asked questions related to students' understanding of the ISTE Standards, including:

- After taking this course, how would you describe the role of the ISTE Standards in the K-12 Classroom?
- Do you agree or disagree that this course helped you understand the ISTE Standards? If so, explain how.
- Will this course impact the way you teach? If yes, in what ways?
- Is there any other information you want to share about this course, its impact on you as a current or future educator, or your understanding of the ISTE Standards?

These specific questions were included to better understand the course's impact on students' understanding of the ISTE standards and their future teaching, which directly aligned with the research question.

Data Analysis

The three authors analyzed the data in four steps: organizing, reading, coding, and creating themes (Creswell, 2009). The first author organized and prepared the data for analysis in a shared spreadsheet. All three authors read through the data to gain a general understanding of it. Subsequently, the authors performed a second review of the data and developed inductive codes that aligned with the research questions (Saldaña, 2021). After identifying initial codes, they consolidated codes, counted their frequencies, and arranged the frequencies from greatest to least in the spreadsheet. This was done to emphasize recurring codes in relation to the research questions. Next, they determined axial codes, established relationships among the codes, and discussed tentative themes based on the data as a whole (Saldaña, 2021; Strauss & Corbin, 1990).

To build trustworthiness, reduce biases, and increase reliability, the authors engaged in triangulation with concurrent data collection, comparing results across data sources, and member checking by engaging in conversations and discussing findings (Creswell & Poth, 2017).

Results

The authors utilized the participants' survey responses from before and after the course to fully understand the impact of the educational technology course on alternative certification students' understanding of the ISTE Standards and the impact on their future classrooms.

Pre-Course Expectations

Pre-survey results showed that most students had not heard of the ISTE standards before taking this course. Additionally, prior to the course, students believed the role of the ISTE standards was to teach teachers how to use technology in the classroom and provide a framework for technology use. Participants stated, "The role of the standards is to give teachers the chance to teach with technology," and another added that the "Standards empower educators to teach with technology," and a third shared that the "Standards provide a roadmap for educators on their expectations and abilities with technology."

In response to the question, "In what ways do you think this course will help you understand the ISTE Standards?" students shared that they believed the course would enhance their teaching, help them understand the ISTE Standards, and educate them on different available tech tools. One student stated, "I hope this course provides me with tools to use in my classroom." Others expressed similar sentiments, stating, "This course is going to give me good examples of these standards and how I can implement them into teaching."

Post-Course Findings

As the authors analyzed the post-course surveys, the course's impact on students' understanding of the ISTE Standards and their teaching became apparent. Upon completion of the course, when asked what was the role of the ISTE Standards in the classroom, students stated the ISTE Standards functioned as a guide for high-quality technology integration, ensured digital safety in the classroom, and helped teachers create equity within the classroom. When asked how this course would impact their teaching in the classroom, students responded the course would lead to increased technology integration in their own classroom, increased student engagement, and increased focus on digital safety. An analysis of the post-course survey responses as whole revealed four themes which are further explained below

ISTE Standards as a guide for equitable technology integration. The post-course survey response demonstrated the impact of the course on student's understanding of the ISTE Standards. 100% of students who completed the post-course survey agreed that the course helped them understand the ISTE Standards and stated that the ISTE Standards served as a guide for educators regarding technology use. One respondent stated, "I would describe the ISTE Standards as an excellent guide in helping educators use technology." Another student shared a similar sentiment, explaining the ISTE Standards as "something to use to make sure we are implementing the right tools and lessons into our classroom." Furthermore, students saw the ISTE standards as a framework that applied to all subjects, with one student explaining, "Now we know better ways to teach the important part of technology to use students no matter what subject we teach." In regard to the ISTE Standards' role in ensuring digital safety and equity, the following responses were noted, "the standards help educators use technology to produce a high-impact and equitable learning experience" and "The standards uphold students to the ethical and proper practice of utilizing technology as students and members of a digital society." These statements emphasize the importance of the ISTE Standards in guiding educators to create equitable, safe, and impactful learning environments that promote ethical use of technology.

Increased focus on intentional technology integration. When asked about the course's impact on teaching, all participants indicated they would increase their intentional use of technology in their classroom. One student shared, "Being a PE teacher, I found it hard to find ways of implementing technology, but due to the fact that I had to think about it and create a lesson plan, I now know how to use it more effectively." Similarly, a student admitted she had trouble with technology before taking the course, explaining, "I had many issues regarding implementing content creation tools before the class…the professor helped me along the way, and I will now be able to integrate technology." These quotes illustrate the course not only provided practical solutions for integrating technology into all content areas, including physical education, but also empowered students to overcome their own self-imposed barriers related to technology integration.

Increased student engagement. Students also felt that understanding and implementing the ISTE standards would increase classroom engagement. Students discussed the role of technology tools in student engagement, stating, "I will now use technology to keep my students engaged" and "I now know specific tools that will aid in student engagement." These quotes highlight the fact that the course introduced students to specific technology tools and provided them the confidence necessary to implement the tools in a way that would result in increased student engagement.

Increased digital safety. The final theme that emerged was related to digital citizenship and digital safety. One student stated, "The ISTE Standards are useful for integrating safe use of technology within the classroom." Others echoed this sentiment, explaining, "This class helped me incorporate digital citizenship into my lessons," and "I will now establish safe technology expectations at the beginning of every semester." This shows the course emphasized the importance of digital safety and equipped students with strategies necessary to teach digital safety and citizenship in their classrooms.

Summary

Overall, the analysis of the pre-course expectations and post-course findings highlight the impact of the educational technology course on alternative certification student's understanding of the ISTE Standards and their teaching practices. The emergence of clear themes, such as the ISTE Standards serving as a guide for equitable technology integration, increased intentional technology use, a focus on digital citizenship, and increased student engagement, highlight the courses' ability to impact students' theoretical understanding and application of the content. One student expressed this sentient sharing, "This was a very informational and real-world course…I was able to implement the learning into my actual classroom." The authors will further discuss the implications of the findings and limitations of the study in the next section.

Discussion

The incorporation of technology-infused courses has attracted attention due to the changing role of technology in education (Williams et al., 2023; Buss et al., 2018). As classrooms develop to meet the demands of 21st-century learning, the intentional incorporation

of technology is critical. However, previous research has shown that effective technology integration does not just happen (Howard, 2020). Many educators require specific instruction on navigating the digital world and effectively implementing technology into their curriculum (Ning et al., 2022).

Previous scholars have shown that technology-specific instruction related to the ISTE standards leads to increased technology implementation in the classroom (Ning et al., 2022). Similarly, the importance of educational technology instruction is recognized by both the Office of Educational Technology and The Texas Educator Agency, as evidenced by their recommendations and mandates (Office of Educational Technology, 2017; State Board of Educator Certification, 2019). This study aimed to understand the impact of an educational technology course on alternative certification students' understanding of the ISTE Standards and the impact on their future classrooms.

Course's Impact on Student's Understanding of the ISTE Standards

Themes answering the first part of our research question detailed the course's impact on student's understanding of the ISTE Standards. Post-course, students understood the ISTE Standards as a framework for classroom technology implementation. They also felt the ISTE Standards were critical to ensuring digital equity and citizenship within the classroom. These findings align with the US Department of Education's (2017) recommendation that alternative teacher educational programs offer specialized technology curricula focusing on ISTE Standards, digital literacy, and technology integration. Furthermore, it confirms that the addition of the educational technology-specific course in an alternative teacher certification program met the State of Texas's requirement for teaching the ISTE Standards and digital literacy (State Board of Educator Certification, 2019).

Course's Impact on Students Teaching Practices

Several themes emerged regarding the impact of the course on students' future classrooms, including increased focus on intentional technology integration, increased student engagement, and increased digital safety. Like other studies, the authors found that a technology-infused course helped prepare students to successfully integrate technology into their classrooms and avoid having a second-level digital divide (Lythreatis et al., 2022).

Conclusion

As alternative educator preparation programs continue to gain traction and the number of alternatively certified teachers continues to increase, programs must ensure their students have the skills to navigate a digital-rich classroom. Findings from this study suggest that one way to accomplish this is by offering a technology-specific course focused on the ISTE Standards. This aligns with Sprague et al. (2023) recommendation that alternative educator preparation programs create opportunities for students to implement technology-infused lesson plans in various subject areas and grade levels.

When implemented correctly, a technology-specific course will empower teachers to educate students in a way that fully prepares them for the 21st Century. As the technology landscape continues to evolve, the days of traditional chalkboard instruction are becoming less common. Educators must leverage digital tools and resources to engage students in dynamic and interactive learning experiences. Technology serves as a catalyst for fostering critical thinking skills, which are critical for success in the 21st century.

Limitations and Future Research

While this study provided insight into the impact of educational technology courses on alternative certification students' understanding of the ISTE Standards, limitations need to be acknowledged. First, the small sample size of participants completing the post-course survey may have limited the generalizability of the findings. Although all students enrolled in the course were invited to participate in the study, only six students completed the survey, potentially introducing sampling bias, as only satisfied students may have completed the survey. Future studies should aim to recruit a larger sample size, increasing the study's validity and generalizability.

Second, the present study relied on self-reported data. Students shared their perceptions and understanding of the ISTE Standards and the impact they anticipated the course would have on their teaching practice. While self-assessment provides insight into the participants' experiences, it may only partially capture the actual impact of the course on future classroom practices. Future studies could use participant-reported data and classroom observations or achievement data to provide a more comprehensive understanding of the course’s impact on future classroom practices.

Finally, this study was conducted as a single institution, which limits the generalizability. Future research should explore the impact of an educational technology course at additional higher education institutions.

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PRESERVICE SECONDARY MATHEMATICS TEACHERS' ANTICIPATIONS OF STUDENT THINKING ON A TECHNOLOGY-ENHANCED TASK

Demet Yalman Ozen
Middle Tennessee State University, USA
dy2i@mtmail.mtsu.edu

Charity Cayton
East Carolina University, USA

Allison W. McCulloch
University of North Carolina at Charlotte, USA

Kristen Fye
University of North Carolina at Charlotte, USA

Purity Muthitu
North Carolina State University, USA

Samantha Fletcher
Middle Tennessee State University, USA

Nina Bailey
Montclair State University, USA

Abstract. The practice of anticipating student thinking is key for planning to inform instructional decisions. However, it is not an intuitive practice for secondary preservice teachers (PSTs). When using technology-enhanced mathematical tasks, the complexity for anticipating student thinking increases as the teacher needs to consider both students' mathematical strategies and technology interactions. This study aims to examine the development of PSTs' anticipations of student thinking on a technology-enhanced mathematics task. Using a framework in a methods course, PSTs were introduced to the practice of anticipating student thinking on technology-enhanced tasks and the connections between anticipating and noticing student thinking. While PSTs either focused on their own thinking or did not anticipate mathematically important components on the pre-assessment, PSTs' focus shifted to student thinking on the post-assessment. Findings suggest that there is promise of introducing a framework to support PSTs' anticipations of student thinking on technology-enhanced tasks and connecting anticipating to noticing student thinking.

Keywords. Preservice Teachers, Student Thinking, Technology-Enhanced Tasks, Mathematics Education, Instructional Planning

Introduction

Anticipating student thinking, a vital component of planning student-centered instruction, is a teaching practice that needs to be developed (Fernandez & Yoshida, 2004; Stein et al., 2008). The process of anticipating requires teachers to consider the myriads of ways students might approach a task and sets the stage for what they will pay attention to as the students engage with that task. When technology is included as part of a mathematical task, this adds an additional layer of complexity for anticipating student thinking. The teacher needs to consider the mathematical strategies, conceptions, and misconceptions students may exhibit, and students' interactions with the technology that inform them. Despite the importance of anticipating student thinking, there is little research to help us understand how PSTs engage in the practice of anticipating (Morrissey et al., 2019), especially in the context of using technology-enhanced math tasks. In this study, we examine the development of PSTs' anticipations of student thinking on a mathematics task, which incorporates technology with dynamically linked representations to explore the concept of vertical asymptotes for rational functions.

Background Literature

Anticipating student thinking (sometimes referred to as informed predicting) is an important teaching practice because it prepares teachers for making instructional decisions informed by student thinking (e.g., Fernandez & Yoshida, 2004; Stein et al., 2008). Anticipating involves:

> Developing considered expectations about how students might mathematically interpret a problem, the array of strategies—both correct and incorrect—they might use to tackle it, and how those strategies and interpretations might relate to the mathematical concepts, representations, procedures, and practices that the teacher would like his or her students to learn. (Stein et al., 2008, pp. 322–323)

In fact, anticipating student thinking is such an important practice that it is identified by name in the Standards for Preparing Teachers of Mathematics (Association of Mathematics Teacher Educators; AMTE 2017), which states that well-prepared beginning teachers of mathematics should be able to "anticipate and attend to students' thinking about mathematics content" (SPTM Indicator C.3.1, p. 18).

As mentioned in this indicator, there is a tight connection between the practice of anticipating student thinking and noticing student thinking (i.e., attending, interpreting, and deciding how to respond) (Jacobs et al., 2010). In fact, Smith et al. (2020) explained anticipating student thinking as "preparing to notice" (p. 50). They explained that anticipating enables teachers to proactively recognize and make sense of student approaches and respond effectively to students. When teachers anticipate student thinking on a mathematics task prior to engaging in noticing student thinking, their noticing improves (Güner & Akyüz, 2020; Jacobs et al., 2010; Ulusoy & Çakıroğlu, 2018).

Scholars strongly agree on the importance of anticipating student thinking, as one of the key aspects of lesson planning for improving the quality of math teaching (e.g., Akyuz et al.,

2013; Taylan, 2018). However, research on the nature of teachers' anticipations is limited. The scant studies that exist have found that teachers and PSTs often focus their anticipations on their own problem-solving strategies (e.g., Şen Zeytun et al., 2010) or solely on student errors (e.g., Janike, 2019; Morrissey et al., 2019). This is consistent with the results of a systematic review of recent studies on teacher competence in mathematics lesson planning that showed the need to support teachers to improve their awareness of student thinking (Cevikbas et al., 2023). In addition, Morrissey et al. (2019) found when anticipating student errors, PSTs often focus on procedural errors without considering students' underlying conceptual understanding. In another study, PSTs struggled to anticipate students' correct thinking in their lesson plans while they were better at providing examples of incorrect student thinking (Taylan, 2018).

The practice of anticipating can be developed by including opportunities to analyze student work (e.g., Didiş Kabar & Erbaş, 2021; Nickerson & Masarik, 2010) or plan lessons (Hughes 2006). Didiş Kabar and Erbaş (2021) investigated PSTs' anticipation of student responses as PSTs engaged in examining and analyzing authentic student work. The PSTs' anticipations shifted from focusing on their own thinking to considering tasks from students' perspectives. Hughes (2006) noted that PSTs demonstrated significant growth in their anticipation of student thinking when planning lessons after participating in a course that emphasized students' mathematical thinking as a key element of lesson planning. Nickerson and Masarik (2010) also found positive shifts in secondary teachers' anticipations after a professional development program designed to improve teachers' interpretations of student thinking by analyzing student work. Teachers initially either focused on where students might have difficulties or did not anticipate student thinking at all. Later, they all articulated potential student responses, both correct and incorrect. Overall, these findings show that asking teachers and PSTs to anticipate student thinking during lesson planning and examining artifacts of student work can result in positive shifts in their practice.

When reviewing the literature, we only found studies focused on anticipating student thinking using paper and pencil tasks. Notably absent are studies on the development of anticipating when using technology-enhanced math tasks. Teachers need to consider both students' mathematical strategies and their interactions with the technology. Given the additional layer of complexity added by technology, we can infer that PSTs need support in the development of the practice of anticipating student thinking on technology-enhanced math tasks.

Conceptual Framework

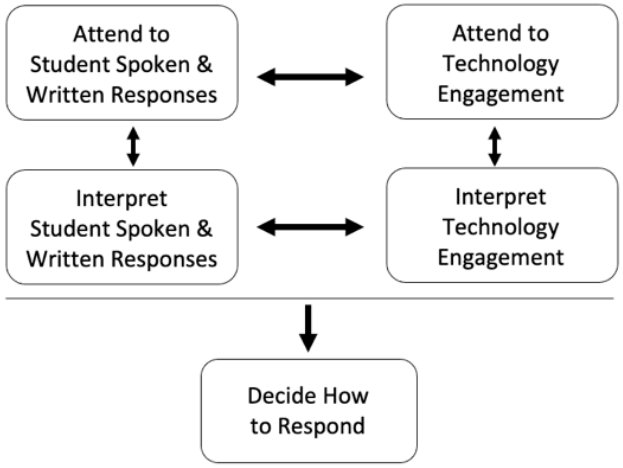
Anticipating is "planning to notice student thinking" (Smith et al., 2020, p. 50). Thomas et al. (2015) linked the attend component of noticing (Jacobs et al., 2010) to anticipating student thinking, noting that one anticipates by "adopting a student's perspective and considering the strategies, questions, and difficult points that may arise as students complete the chosen task" (p. 240). We are interested in PSTs' anticipations on technology-enhanced math tasks involving technology that responds to user actions in mathematically defined ways (math action technology; Dick & Hollebrands, 2011). When anticipating such tasks, adopting a students' perspective includes "anticipating the ways you expect students to engage with the technology, where their eyes might be drawn, what representations they might favor, and how they will make sense of their actions with the technology" (PTMT-ESP, 2023, p. 5).

From a practice-based approach (Grossman et al., 2009) to preparing PSTs to teach mathematics with technology, PSTs need opportunities to enact core components of the work of teaching in simplified contexts. As a core teaching practice, anticipating prepares PSTs for making instructional decisions informed by student thinking (e.g., Fernandez & Yoshida, 2004; Stein et al., 2008). The practice of anticipating has been identified as an essential component of multiple student-centered instructional frameworks, including Simon's (1995) Hypothetical Learning Trajectory, the structured problem-solving lessons used in Japanese Lesson Study (Fernandez et al., 2003), and the 5 Practices for Orchestrating Productive Mathematics Discussion (Stein et al., 2008). Given its relationship to other core practices, it is important to provide PSTs with scaffolded opportunities to study and practice (Forzani, 2014).

From a practice-based perspective, to support PSTs in developing their anticipating practice, PSTs must first build an understanding of the practice through analyzing representations of the practice—unpacking (or decomposing) them into their constituent parts (Grossman et al., 2009). Because anticipating student thinking serves the purpose of planning to notice student thinking, noticing frameworks could support PSTs in their decomposition of the practice of anticipating (Thomas et al., 2015). To support PSTs in building an understanding of the practice of anticipating student thinking on technology-enhanced math tasks, we used the Noticing in Technology-Mediated Environments (NITE) framework (Dick et al., 2021; Dick et al., 2022; McCulloch et al., 2023). The NITE framework (Figure 1) builds on Jacobs et al.'s (2010) conceptualization of noticing students' mathematical thinking and highlights that students' mathematical thinking can be expressed through their engagement with math action technologies. We follow Grossman et al.'s (2009) framework by having PSTs first build an understanding of the practice of anticipating student thinking on technology-enhanced math tasks using the NITE framework, then approximate the practice of this practice by providing opportunities for deliberate practice in a safe environment.

Figure 1

The Noticing in Technology-Mediated Environments (NITE) Framework



Methods

Participants and Context

This qualitative study examined the anticipations of PSTs at the beginning and end of a methods course in which PSTs learned about anticipating student thinking on technology-enhanced math tasks. The participants included 12 secondary PSTs enrolled in one of the three methods courses at three different universities. The PSTs were familiar with anticipating student thinking on paper and pencil tasks prior to this course (Smith et al., 2020). During the course, PSTs engaged with curricular materials designed to extend the practice of anticipating into technology-mediated tasks.

The curricular materials included eight modules designed to engage PSTs in carefully crafted approximations of practice focused on anticipating and noticing student thinking in technology-mediated environments (PTMT-ESP 2019; see References for a link to the website with a full description of the design of the materials used in the course). The first module explicitly introduced PSTs to the practice of anticipating student thinking on technology-enhanced math tasks and the connections between anticipating and noticing student thinking using the NITE framework (Dick et al., 2021; Dick et al., 2022; McCulloch et al., 2023). The seven remaining modules focused on specific algebra and functions and topics (e.g., algebraic equivalence; comparing/contrasting linear, quadratic, and exponential rates of change; key features of quadratic functions; trigonometric functions; and characteristics of function families). Each module followed specific design principles that included engaging with a technology-enhanced task as a learner, anticipating student thinking on the task, and then noticing student thinking on the same task using carefully selected video clips of middle and high school students engaging with the task.

Throughout the course, PSTs included at least five opportunities, not including the pre- and post-assessment, to engage in the practice of anticipating and noticing student thinking on technology-enhanced algebra and function tasks throughout the semester. The purpose of this study was to investigate the development of PSTs' anticipation of student thinking on technology-enhanced tasks when explicitly introduced to the practice of anticipating as a means of planning to notice student thinking.

Data Collection and Analysis

The data consisted of screen recordings of PSTs' anticipations of student thinking on a technology-enhanced task designed to be an introduction to vertical asymptotes for secondary students. PSTs completed screen recordings once at the beginning of the course and once at the end (i.e., pre- and post-assessment). The instructions for the assessment stated:

> Part of planning to use a technology-enhanced task is to anticipate student thinking. Take some time to work through the task yourself. Screencast record yourself as you do so. As you work, make sure you talk aloud to share your thinking.

Because of the nature of a screencast assessment, we only had access to what PSTs shared while engaging in the task, and we could not probe their thinking as they screen recorded themselves.

The task was built in Desmos Classroom and included several pages with prompting questions and definitions. The early pages contained a warm-up and the definition of vertical asymptote (Figure 2). Subsequently, a page featuring a Desmos Graphing Calculator presented dynamically linked representations (e.g., graphical, numerical, and symbolic) for the function, $f(x) = k / (ax+b)$. This dynamic page prompted users to manipulate the three sliders for parameters k, a, and b (see Figure 3). For this study, we only focused on this page of the task.

Figure 2

The Definition Page from the Introduction to Vertical Asymptotes Desmos Task

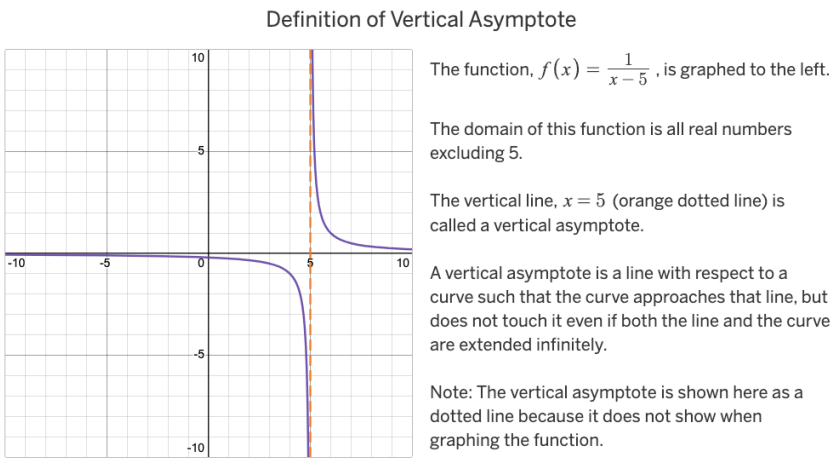
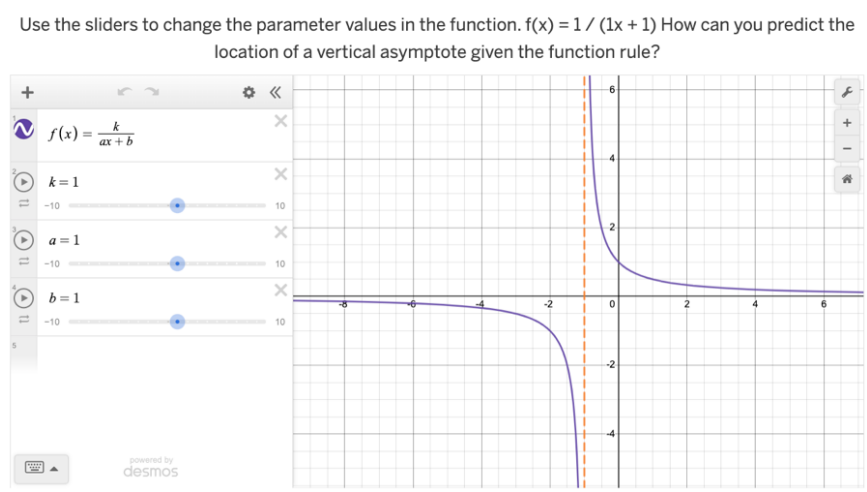


Figure 3

The Math Action Technology Page from the Introduction to Vertical Asymptotes Desmos Task



The screencast data were analyzed using a three-step process. First, we identified the mathematically significant details (Leatham et al., 2015) that would be important to consider when anticipating how students might interact with the dynamic sketch and what they would see as a result of those interactions (e.g., dragging all of the sliders, parameter changes in the hot text). Second, we created a rubric to capture the various strategies and representations that PSTs might include in their anticipation of student thinking on the task.

The coding rubric (Table 1) included anticipation of strategies using dynamic graphical representations (e.g., testing key values on sliders), numerical representations (e.g., using a cursor or slider to test specific values), and symbolic representations (e.g., sensemaking about the dynamic function rule). For each strategy, we also coded the focus of the PSTs' anticipation (i.e., no evidence, self, student, both). This is like Didiş Kabar and Erbaş's (2021) coding, although they refer to this as an "approach". For example, exploring key values was considered mathematically important. Thus, testing $a=0$ was included in the rubric. An example of each of the focus codes including a description of what the PSTs would say and/or do to receive a given code follows:

> *No Evidence*: There was no evidence in the video of the PST considering $a=0$ in their anticipation (e.g., either did not use the sliders at all or did not stop on $a=0$ as they did use them).
>
> Focus on *Self*: The PST drags slider a, pauses on $a=0$ and sees a horizontal line on the graph and says "oh", then continues to drag the slider to the left.
>
> Focus on *Student*: As the PST drags the sliders, they say "Depending on how comfortable they are with sliders, they might set them all to 0 and see what is happening. They might note that when a is 0 it is a horizontal line. I think that is an important thing for students to notice. It's something I'd want students to notice so I can build on that later, about why that is."
>
> Focus on *Both*: The PST is dragging all 3 sliders. When doing so, they stop at $a=0$ a few times, pausing while changing the other parameters. The PST then sets both a and b to 0 and says "everything goes away and they're going to go 'huh, that's interesting'". The PST then drags b to the right and adds "there needs to be some value down here for there to be any sort of graph at all and a needs to be something in order for there to be a vertical asymptote. If a is 0, then all you have is a vertical line that moves around."

Finally, we watched the screencasts and applied the rubric to code the PSTs' anticipations. Each video was coded by two members of the research team, and codes were recorded in a spreadsheet. Codes were then compared, and any discrepancies were discussed and reconciled with the other research team members.

Results

The evidence and focus of the PSTs' anticipations on the vertical asymptote task are summarized in Table 1. We identified six mathematically significant details that would be

important to consider when anticipating, which resulted in 72 instances to analyze across 12 PSTs. On the pre-assessment, there were only three instances (4%) of the PSTs focusing on students' thinking in their anticipations. Instead, PSTs either focused on their own thinking (33 instances; 46%) or did not include important thinking in their anticipations at all (36 instances; 50%). On the post-assessment, PSTs' focus on students' thinking in their anticipations demonstrated a 10-fold increase (30 instances; 42%), with only 21% (15 instances) focusing on their own thinking and 37% (27 instances) not including important thinking in their anticipations. Findings with respect to thinking with the dynamic representations are included in the sections that follow.

Anticipations with Graphical Representations

When examining PSTs' anticipations within graphical representations, we considered if PSTs tested all sliders, including key values (*a=0, k=0*). With respect to anticipations related to the testing of all sliders, we saw positive changes from the pre- to post-assessment. On the pre-assessment, four out of 12 (33.3%) PSTs did not test any sliders, compared to only two (16.6%) on the post-assessment. Additionally, six PSTs (50%) tested sliders for themselves only, in contrast to two (16.6%) on the post-assessment. Most promising was that only two PSTs (16.6%) tested sliders from both self and student perspectives on the pre-assessment, but eight (66.6%) did so on the post-assessment. Thus, we saw both an improvement in the number of PSTs testing the sliders regardless of focus, as well as more PSTs focusing on students' responses rather than just themselves.

For testing key values (*a=0, k=0*), results were mixed. These key values were included because it is important to anticipate student thinking at values for which the preconstructed file "breaks" (i.e., the function is no longer rational, but a vertical line still shows in the plane). The number of PSTs that did not test key values for *a=0* increased from three (24%) to six (50%) from pre- to post-assessment. Those that focused on testing *a=0* from the perspective of self declined from eight (66.6%) to three (25%), and those that focused on both self and student increased from one (8.3%) to three (25%). A similar pattern was noticed for *k=0*. While it is promising that the focus on self and student increased in both cases, we are not sure why half of the PSTs chose not to test the key values for *a=0* and *k=0* on the post-assessment.

Table 1.

Anticipations Related to Different Representations on the Desmos Introduction to Vertical Asymptotes Task

Graphical Representations			Numerical Representations	Symbolic Representations	
Test all sliders	Test key values (*a=0*)	Test key values (*k=0*)	Use cursor/slider to identify individual points to use to test values	Identify the dynamic rule at the top of the page	Evidence of use (or not) of the dynamic function rule at the top of the page

PST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
1	Self	Self	Self	N/E	Self	Self	Self	Self	N/E	Self	N/E	N/E
2	Self	Student	Self	Student	N/E	Student	Self	Student	N/E	Student	N/E	Student
3	N/E	N/E	N/E	Self	N/E	N/E	Self	Both	N/E	Self	N/E	Self
4	Both	Both	Both	Both	Self	N/E	Self	Both	N/E	Both	N/E	Student
5	Both	Self	Self	Self	Self	N/E	Self	Self	N/E	N/E	N/E	N/E
6	Self	Both	Self	Self	Self	N/E	Self	Both	N/E	Student	N/E	Student
7	Self	Both	Self	N/E	Self	Self	Self	Self	N/E	N/E	N/E	N/E
8	Self	Both	Self	N/E	Self	N/E	Self	Student	N/E	Both	N/E	Both
9	Self	Both	Self	Student	Self	Student	Self	Student	N/E	Student	N/E	Student
10	N/E	Both	N/E	N/E	N/E	N/E	N/E	Self	N/E	N/E	N/E	N/E
11	N/E	N/E	N/E	N/E	N/E	N/E	Self	Student	N/E	N/E	N/E	N/E
12	N/E	Both	Self	N/E	Self	N/E	Self	Self	N/E	N/E	N/E	N/E
N/E	4 33.3%	2 16.6%	3 25%	6 50%	4 33.3%	8 66.6%	1 8.3%	0 0%	12 100%	5 41.6%	12 100%	6 50%
Self	6 50%	2 16.6%	8 66.6%	3 25%	8 66.6%	2 16.6%	11 91.6%	5 41.6%	0 0%	2 16.6%	0 0%	1 8.3%
Both/ Student	2 16.6%	8 66.6%	1 8.3%	3 25%	0 0%	2 16.6%	0 0%	7 58.3%	0 0%	5 41.6%	0 0%	5 41.6%

Note. N/E means no evidence.

Anticipations with Numerical Representations

PSTs' anticipations of students' responses with numerical representations in the vertical asymptotes task resulted in a large shift from PSTs focusing on self to a focus that included student responses. Only one PST (8.3%) showed no evidence of anticipations with numerical representations (e.g., using the cursor to identify specific ordered pairs) on the pre-assessment, 11 PSTs (91.6%) did so with a focus on self, and none of them did so with a focus that included anticipations of student responses. However, on the post-assessment, all PSTs anticipated in some form with five (41.6%) focusing on self and seven (58.3%) focusing that included student responses.

Anticipations with Symbolic Representations

With respect to the symbolic representations, analysis attended to identifying the symbolic representation (i.e., the dynamic function rule at the top of the page) and using it. On the pre-assessment, none of the PSTs identified or provided evidence of the use of the dynamic function rule at the top of the task page (see Figure 3). On the post-assessment, five PSTs (41.6%) and six PSTs (50%) did not identify or provide evidence of using the dynamic function rule, respectively. However, two PSTs (16.6%) identified and one (8.3%) provided evidence for using the dynamic function rule with a focus on self on the post-assessment. The largest positive shift was seen in anticipations that included student responses with the symbolic representation on the post-assessment. Five (41.6%) PSTs both identified and provided evidence for using the dynamic function rule.

Discussion and Implications

PSTs' anticipation of student thinking is an important part of planning for student-centered instruction. Anticipating is not an intuitive teaching practice, as PSTs often focus on their own responses rather than students' thinking but can be developed through coursework or professional development (Didiş Kabar & Erbaş, 2021; Hughes, 2006; Nickerson & Masarik, 2010). What has been under-studied to date is PSTs' anticipating practices on technology-enhanced math tasks. In this study, we set out to understand how introducing PSTs to anticipating student thinking on technology-enhanced math tasks through connecting it to the practice of noticing student thinking might support their development of the practice of anticipating. What is clear and consistent across PSTs' anticipations for the various dynamic representations is that there was an increase from pre- to post-assessment for PSTs' focus to include student responses (i.e., focus codes of "student" and "both"). These findings suggest that this instructional approach may be a fruitful one to further develop PSTs' anticipation of student thinking.

When examining PSTs' anticipations on the dynamic elements in the Introduction to Vertical Asymptotes task, we looked at both the representations they included in their anticipations, as well as the focus of those anticipations. On the pre-assessment, most of the PSTs focused their anticipations on their own thinking; this finding is similar to prior studies on teachers' and PSTs' anticipations on paper and pencil tasks (Didiş Kabar & Erbaş, 2021; Şen Zeytun et al. 2010). However, on the post-assessment PSTs' focus shifted greatly from their own thinking to student thinking. This shift is consistent with other studies that included opportunities to examine authentic student work as PSTs worked on their anticipating practices (e.g., Didiş Kabar & Erbaş, 2021; Hughes, 2006; Nickerson & Masarik, 2010; Ulusoy & Çakıroğlu, 2018).

When we look at the specific representations that PSTs included in their anticipations, the largest difference from the pre- to post-assessment was anticipations related to the numerical representation. There was evidence that all PSTs anticipated using the numerical representation on the post-assessment, with more than half focusing on student thinking. None of them showed this evidence on the pre-assessment. The second largest shift from pre- to post-assessment was anticipations related to the graphical representations. Two-thirds of PSTs showed evidence of anticipation with a focus on student thinking related to testing sliders, including key values in the post-assessment. With respect to the symbolic representation, none of the PSTs showed evidence of anticipation with the function rule on the pre-assessment, while just under half did on the post-assessment. In the context of vertical asymptotes, the function rule itself is important to consider because it is key to anticipating conceptual understanding (i.e., the location of the vertical asymptote is related to the domain of the function). The absence of the PSTs anticipating student thinking with the dynamic function rule aligns with prior research indicating a tendency to prioritize procedures over underlying concepts (Morrissey et al., 2019). It is promising that about half of the PSTs' anticipations included the function rule on the post-assessment, suggesting a potential for recognizing students' thinking related to this important conceptual connection. Anticipating student thinking with respect to all these different dynamic representations is crucial, as it is part of planning for making connections among multiple representations, a practice that has been found to be essential for supporting student learning in the context of algebra and function (Goldin & Shteingold, 2001; Knuth, 2000; Lesh et al., 1987).

Findings from this study suggest that explicitly introducing the NITE framework to support PSTs' anticipations of student thinking on technology-enhanced mathematics tasks and connecting anticipating to noticing student thinking has promise. Furthermore, research has shown that PSTs' noticing improved when introduced to the NITE framework, though it is still not consistently robust (Bailey et al., 2022; Dick et al., 2022). Based on these findings, additional research is needed to examine the tie between anticipating and noticing, specifically how supporting PSTs' anticipating influences their noticing of student thinking on technology-enhanced mathematics tasks. In addition, prior research on both anticipating and noticing has shown that PSTs often do not show evidence of anticipating or interpreting students' conceptual understandings (Morrissey et al., 2019). Insight into students' conceptual understandings requires anticipating more than just correct and incorrect responses to a task. Future research should consider how we might leverage noticing frameworks to support PSTs' anticipating, attending to and interpreting students' conceptual understandings—especially those they do not yet understand.

Conclusion

The findings from this study demonstrate that anticipating student thinking on technology-enhanced tasks can be learned. To this end, the use of materials that explicitly introduce the practice of anticipating student thinking on technology-enhanced tasks and the connections between anticipating and noticing based on the NITE Framework have the potential to improve PSTs' anticipating practice.

Limitations

This study has some limitations that should be acknowledged. First, the sample size was small. Future research should aim to include a larger sample. Second, the insights into the PSTs' anticipations were constrained by the nature of the data collection method. The study relied on screen recordings to capture PSTs' practices, limiting the analysis to what the participants explicitly expressed during these recordings. The absence of follow-up questions due to this modality prevented a deeper exploration of their anticipations. Future studies can incorporate additional data collection methods to gain more insights into PSTs' anticipations.

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MEET THEM WHERE THEY'RE AT: CREATING HUMAN-CENTERED ONLINE PD FOR RURAL TEACHERS USING LXD

Mia Kim Williams
University of Wyoming, USA
Mia.Williams@uwyo.edu

Carrie Kell
University of Wyoming, USA

Abstract. Rural communities struggle with K12 teacher retention. While salary persists as an issue leading to attrition, mental health, workload, community, and professional support also have a significant impact. This study presents findings about a project in which teachers and university facilitators co-constructed competencies teachers identified as necessary to support their work in classrooms. The research strives to address the critical need for professional learning opportunities that are both accessible and adaptable, addressing the unique needs of rural teachers, students, and districts to improve teacher retention and mitigate issues arising from teacher attrition. The state competencies created by participates informed the development of responsive, adaptive online professional learning opportunities. The research both explains the co-creation of teacher competencies and explores how human-centered approaches and learning design practices, such as design thinking and learning experience design (LXD). This foundational work provides opportunities for future research to explore the effectiveness of learning modules and their influence on teacher attrition.

***Keywords*.** Learning Experience Design, Rural Education, Professional Development, Teacher Retention

Introduction

Like many rural communities, Wyoming is facing an immediate and long-term challenge related to the success and retention of K12 teachers. In fact, in a recent survey, 65% of Wyoming teachers agreed that if they could quit, they would (Perkins, 2022). Rurality compounds many issues caused by teacher attrition. For example, rural school districts have smaller numbers of teachers per subject area, and often one teacher teaches all courses in a subject. Often, a solution for being short staffed within a school is to increase the class size of other teachers who teach the same subject, but the reality of rural contexts creates challenges for teachers to pick up the slack of a missing faculty without teaching out of their field. "If a school doesn't have someone to teach science, for example, expanding the size of history classes does not help" (Thomas, 2023, para. 8). Additionally, while salary is a concern across education, the survey indicated mental health, workload, building community, and professional learning opportunities are significant contributing factors (Perkins, 2022). These additional factors underscore the importance of accessible and adaptable professional learning opportunities that cater to the unique needs of rural teachers, students, and districts to both retain teachers and solve problems created by attrition. This applied research paper shares the initial phase of an ongoing project to respond to teachers' learning needs across the state. It provides a detailed exploration of how Learning Experience Design (LXD) principles and strategies were effectively utilized in the creation of a comprehensive Master Educator Competency Program (MECP) to identify and support the unique needs of rural districts and their teachers.

When creating online professional development, instructional design principles are often used. Traditional instructional design procedures are primarily influenced by the content, aiming to generate instructional materials (Hickey & Correia, 2024). These frameworks often follow a systematic model focused on objectives, assessments, and instructional strategies, which can be restrictive and fail to account for the complex and dynamic nature of teaching, especially in rural settings. In contrast, LXD offers a more holistic and flexible approach that aligns with the multifaceted experiences of educators and learners as it "looks beyond the learning objectives, instructional components, sequence, etc.—the foci of the learning designer—and instead considers the learner's experience as an explicit outcome" (Hickey & Correia, 2024, p. 13). Professional development in education is not one-size-fits-all solution and should not be created solely based on human experience, not hype or buzzwords. This paper explores how LXD, with its emphasis on empathy and co-creation, provides a framework for developing professional learning opportunities that resonate with the unique needs of rural educators.

Master Educator Competency Program

The University of Wyoming, in collaboration with 2Revolutions (*2Revolutions*, n.d.) and seven school districts across the state, created teacher competencies that drove the development of adaptive and responsive online professional learning pathways. The project attends to Wyoming's teacher retention and attrition in rural areas by addressing teachers' primary concerns and specific district needs. How did we know what their needs are? We asked them. MECP began with face-to-face listening sessions held in the participating districts around Wyoming. Developing professional learning collaboratively with the districts makes visible what is needed to support master teachers, according to them. Using the co-constructed competencies and

applying LXD principles and strategies, a uniquely designed product is evolving to address teachers' issue and learning needs through competency-based micro-learning experiences that are contextual and adaptive.

The co-construction of competencies took place in a five-part design process grounded on design thinking and human-centered LXD principles, including empathize, ideate, and prototype (Anderson et al., 2017; Hickey & Correia, 2024). The process began with a full-day, face-to-face design session with teachers and administrators held in their district. For some districts, this involved a representation of teachers and administrators, but for smaller districts, it included all teachers and administrators. These sessions produced a district-specific set of competencies. Table 1 lists district-specific competencies in a representative area, learner communication, collaboration, and creativity, that were collaboratively created during the design sessions at each district and used to create the state-level competencies related to collaboration, communication, and creativity.

Table 1

District Competencies Related to Collaboration, Communication, and Creativity

State Core Competency: Collaborate, communicate, and create in a learner-centered system	
Participating district	***Functional Competencies from district specific collaborative design related to collaboration, communication, and creativity***
1	Design experiences that provide opportunities for learners to build globally-transferable skills--including communication, collaboration, self-direction, critical and creative thinking--that they will need to be successful in college, career, and the workforce Recognize that in order to be prepared for the evolving landscape of work, content knowledge is not enough, and students need to be able to use this knowledge to solve novel problems and effectively communicate their ideas Intentionally teach students not what to think, but rather how to ask questions and think for themselves
2	Provide opportunities for students to think critically and creatively about the content and skills they are taught student engagement Collaborate and communicate effectively with colleagues and community around their needs and the needs of the students Create opportunities to collaborate with colleagues across disciplines and grade levels
3	Create opportunities for students to collaborate and work across differences to solve complex problems student engagement

	Embed communication and other soft skills into content-focused instruction Provide spaces that encourage and support discussion and engagement with soft skills, such as communication, collaboration, and analytical thinking
4	Develop problem-solving and critical thinking skills to provide learners with the tools to solve novel student engagement challenges Intentionally instruct and infuse the skills of meaningful collaboration, effective communication, innovative solution-making, and strong self-directing into a variety of learning experiences in order to build globally- transferable skills
5	Cultivate deeply collaborative learning environments where all participants have both a productive role student engagement and the opportunity to develop leadership skills Create spaces and opportunities for all learners to express their ideas by becoming more effective communicators and leaders
6	Facilitate learning that not only teaches content but that teaches learners how to think creatively and solve problems Build strong foundations in literacy across content areas to support obtaining, evaluating, and synthesizing information from a variety of sources
7	Design meaningful and authentic learning opportunities that create spaces for learners to master student engagement globally-transferable skills including collaboration, communication, and creative problem solving Understand that creativity is not just for the arts but helps students to think differently, be better problem solvers, and express themselves in meaningful ways

Note: This table includes an example of the unique district language in one comparable area- collaboration, communication, and creativity- which all participating districts included in their competency design.

Each district's competencies were cross-analyzed to create a state-level Portrait of an Educator to serve as guidance for any districts within the state. (See Appendix A.) The state-level competencies were used as guidance for designing the professional learning offered to teachers.

These professional learning opportunities intend to meet the needs of local schools, educators, and students in rural communities. University faculty created, and continue to create, module content—aimed at addressing the local needs identified by participating teachers in the collaborative competency developed process. 2Revolutions designed and maintains the learning management system used for delivering professional learning opportunities. The professional learning leverages adaptive AI-driven tools to best attend to teachers' knowledge level of content, embracing a competency-driven approach. At the time of this publication, eight modules

were prototyped and tested with participating districts. Forty-eight modules were in various stages of development based on the feedback of the prototype testing.

Significance of the Study

The findings of this study and the subsequent phases of the project could have significant implications for educational policy and practice, particularly in rural areas. Involving educators in significant ways to identify their professional learning needs, the project empowers them and acknowledges their expertise, which might lead to increased job satisfaction and retention. Although the study is localized to one state, this approach to professional development design has the potential to be scaled and adapted to different rural contexts and contributes to a larger conversation about teacher attrition and retention.

Literature Review

This literature review will explore the scope of research on teacher retention and the unique challenges of rural educators. Additionally, the role of competency development as a strategic tool for retaining educators is emphasized in the literature (Casely-Hayford et al, 2022; Frahm, & Cianca, 2021; Ingersoll & Tran, 2023; Podolsky et al., 2019; Seelig, & McCabe, 2021), suggesting that when teachers receive human-centered professional development, they are equipped with a specific set of cognitive, emotional, and social skills specific to their students and unique needs in rural education.

Teacher Retention

Teacher retention is not a new topic of concern in education, and significant research examines the topic as an unrelenting problem with short-term and long-term consequences (Ingersoll & Tran, 2023; Nguyen et al., 2020; Sorensen & Ladd, 2020). Kelchtermans (2017) further argues that this is an educational issue that is both a problem and a challenge. Research suggests that with teacher turnover, "a particular school may reduce the quality of education the school can offer, with resulting adverse impacts on outcomes for the school's students" (Sorenson & Ladd, 2020, p. 1). Understanding the why has been a focus of much scholarship. In a recent study, Ingersoll and Tran (2023) concluded that while the rise in student enrollment is often considered a cause of teacher shortage, the data indicate that the primary reason for recruiting new teachers in rural schools at the start of the school year is to cover the vacancies left by other instructors who left their schools at the conclusion of the previous school year. A main cause of this turnover is job dissatisfaction (Ingersoll & Tran, 2023).

Rural educators often face unique experiences and subsequent challenges in teacher recruitment and retention (Tran et al., 2020). Because rural education has distinctive qualities, developing knowledge in rural teaching can positively affect teacher recruitment and retention (Barter, 2008). Professional development emerges as a strategy for mitigating the issue of teacher turnover as argued by Shaha and Ellsworth (2013), whose research concluded that higher engagement and utilization of professional learning might lead to improved retention and effective teachers. The complex needs of educators at various phases of their careers can be addressed via professional learning that is engaging, continuing, and relevant.

Competencies

Professional development in teaching is a critical factor influencing both teacher retention and the efficacy of education. Kelchtermans' (2017) examination of teacher retention and attrition as an educational problem underscores the importance of professional learning and continued development for experienced teachers. Additional research contends that mid-career teachers are more confident in their classrooms and may overlook professional development opportunities compared to novice teachers. Evidence also suggests that professional development may help support the retention of this population (Booth et al., 2021). These "second stage" teachers require different types of professional development as they do not experience the same issues as beginning teachers (Eros, 2011). Designing new professional learning pathways for the MECP is rooted in customized teaching competencies that are specific to rural educators. Moghtadaie and Taji (2018) characterize "teacher competencies as a set of cognition, orientation, and skills that a teacher can achieve in the process of education to promote the physical, intellectual, emotional, social, and spiritual development of students" (p. 565). The development of these competencies is not just intrinsic to educational quality but also plays a pivotal role in teacher retention, especially in rural districts. Developing such competencies may promote teacher retention in rural districts, as rural teachers stay because of their commitment to students and their desire and motivation to help their students succeed (Seelig & McCabe, 2021).

Human-Centered Professional Development

Professional development opportunities for teachers can often feel like a passive experience, especially when their focus can often feel removed from their experiences or created based on hot topics in the field. Needs-based professional development responds to the unique needs of teachers, schools, and districts (Lee, 2004). This human-centered approach is foundational to learning design practices such as design thinking and LXD. As a conceptual framework, LXD is human-centered and goal-oriented. LXD puts people at the center of design, similar to design thinking. Floor (2023) states that this means that as a designer, we must "Get to know the learners, the people you design for (and) be able to empathize with them as learners" (p. 108). A key feature of LXD as a design practice is connecting through interviews, observations, and being rooted in the co-creation of learning. It is essential to be able to recognize and respond to differing needs among learning groups and even individual learners (Shapers, n.d.). This process is iterative because designers collect and analyze data, conduct user testing, and gather feedback from learners (Hickey & Correia, 2024). Humans are at the center throughout the process. In designing professional development opportunities based on LXD and a needs-based approach, the experiences of educators drive the learning outcomes.

Theoretical Framework

Human-centered LXD places learners at the heart of the educational process, emphasizing empathy, personalization, and iterative development to create engaging and effective learning environments (Hickey & Correia, 2024). This approach integrates principles from user experience design and instructional design to address the specific needs, contexts, and aspirations of learners (Norman & Spohrer, 1996). At the core of human-centered LXD is a deep understanding of learners. Empathy allows designers to identify and address learners' needs,

preferences, and challenges. By employing methods such as interviews, observations, and learner profiles, educators can create more relevant and impactful learning experiences (Bovill et al., 2011). This empathic approach aligns with other research emphasizing the importance of understanding student experiences to improve learning outcomes (Hickey et al., 2024; Kumar, 2023; Cook-Sather et al., 2014).

Human-centered LXD involves learners in the design process, ensuring that their voices are heard, and their needs are met. Co-creation fosters a sense of ownership and engagement among learners leading to more effective and meaningful educational experiences (Bovill, 2020). Collaboratively designing learning, as in MECP's approach to co-constructing competencies, is supported by research highlighting the benefits of student participation in curriculum design, which can lead to increased motivation and satisfaction (Cook-Sather et al., 2014; Kumar, 2023). Additionally, an iterative design process is fundamental to human-centered LXD. This involves similar processes to design thinking such as prototyping, testing (Anderson et al., 2017), and refining learning experiences based on continuous feedback from learners (Brown & Green, 2016). Iterative design ensures that educational interventions remain responsive and adaptive to changing learner needs and contexts. Research by Laurillard (2012) underscores the value of iterative development in creating effective learning environments that evolve with learner feedback. Human-centered LXD emphasizes the practical application of knowledge and skills, aligning educational content with learners' professional and personal goals (Kolb & Kolb, 2005). This approach resonates with the experiential learning theory, which advocates for learning through direct experience and reflection (Kolb, 1984).

Human-centered LXD also prioritizes the creation of interactive and multimodal content that engages learners and facilitates deeper understanding (Kumar, 2023). Incorporating elements such as simulations, quizzes, and hands-on activities can make learning more dynamic and effective (Mayer, 2020). Human-centered LXD integrates empathy, co-creation, iteration, personalization, practical relevance, and interactivity to create effective and engaging educational experiences (Cook-Sather et al., 2014). By employing this framework and focusing on the holistic needs of learners, our approach to co-creation, which draws on the iterative process in collaboration with districts, fosters environments that intend to be meaningful and motivating as well as educationally effective.

Methods

The purpose of this study was to understand the professional learning needs of in-service teachers in rural communities through an experiential co-construction of competencies that were used to design adaptive, asynchronous, professional learning opportunities. We used qualitative methods, framed within an LXD framework, through which K12 teachers and administrators provided individual and collaborative perspectives on what they needed to learn to effectively support students. The LXD design process begins with a desired learning outcome (Shapers, n.d.). The goal was to elicit rich, descriptive data honoring the participants' priorities, visions of future K12 graduates, and professional language. Data collection was human-centered, and sessions were conducted throughout Wyoming in locations representative of the state's typical rural communities; 7 of the 47 districts fully participated. After the initial data collection, a reflective qualitative analysis approach was used to examine the data.

Participants

Wyoming teachers face unique challenges and opportunities influenced by the state's geographic, demographic, and economic characteristics. Our intention with recruitment of participants was to be reflective of the broader experiences and perspectives of Wyoming educators. With a total of approximately 8,000 teachers statewide, this population provides a rich context for exploring various aspects of educational practices, teacher development, and policy impacts. The participants of this study were a representative sample of this population. Districts throughout the state were all invited to participate, and seven districts chose to collaborate. Thus, participants, all of whom were employed in public schools across the state of Wyoming, included seven superintendents, or their designated representatives, and 132 building level teachers and leaders ranging in experience from first-year to 20+ year veteran teachers. This provided us with participants representing a range of diverse educational settings from rural remote districts to small city districts (NTPS, 2022). The most rural districts in the sample were composed of one school serving a vast geographical area where elementary teachers teach in multi-grade classrooms and secondary teachers are responsible for all courses taught in a content area. In contrast, participating small city districts were comprised of between 10 and 38 schools, with a more traditional structure of multi-classroom elementary, middle, and high schools, with multiple teachers teaching single grade classrooms or courses dedicated to one discipline or content area.

Data Collection

Data collection took place throughout the sessions with the participants as we captured their idea generation notes and the collaborative synthesis that directly informed the competencies. Data collected included scans of sticky-note idea clouds and poster paper drafts of competencies (collaborative synthesis).

Prior to data collection, participants envisioned and discussed the knowledge, dispositions, and skills of high school graduates from their district. This exercise brought participants' focus to the desired outcome of the project. The teachers' ideas aligned with the parallel work of the Wyoming State Board of Education to create a Profile of a Graduate specific to the state. The Wyoming Profile of a Graduate includes four areas, a) learn, b) work, c) contribute, and d) thrive, with corresponding objectives (*Wyoming Profile of a Graduate*, 2023). The dispositions and skills identified by teachers during the first session did not use the same language, nor were they organized the same way, but they addressed similar desired outcomes of graduates. This is noteworthy because the population of the state work included many stakeholders and the sessions associated with this project were limited to teachers and administrators. These comparisons included skills such as, transferring knowledge across content areas, identifying credible sources, collaborating with a variety of people, and building and maintaining healthy relationships. Likewise, the dispositions of state stakeholders and project teachers had similarities (e.g., growth mindset, exceeding expectations, or advocacy for self and others). This activity brought participants toward a collaborative understanding about their students, then, participants were asked to think of the needs of the educators (i.e. think of themselves) to support the growth and development of the graduates they just described in their district.

Data used for this study was initially generated individually by participants writing ideas of what they might need to learn as educators to meet the needs of their future graduates, as envisioned by the state and their district. These words and phrases served as the first attempt to generate ideas. Teachers then worked in small groups to look for patterns. Participants had the opportunity to keep, change, or remove ideas as they advanced through the process. The individuals' ideas were first written on sticky-notes with one idea per note, then combined by combining multiple notes together in idea clouds. Participants could remove or add new notes at any time during this idea generation process. The data was collected by scanning images of the idea clouds from each small group.

Data Analysis

Data analysis used a two-cycle coding process that was conducted by the participants as they worked collaboratively with session facilitators. Initial coding (Saldaña, 2016) utilized each segment of the data created by individual participants, where each represented a unique thought or concept. Participants organized these data in small groups, creating codes. Descriptive coding was primarily utilized during this phase, where a word or short phrase was used to describe a group of data segments.

Following the initial coding, a second cycle of coding was implemented using focused coding (Saldaña, 2016). This involved the identification of the most frequent or significant codes across all participants, synthesizing them, and exploring possible relationships or patterns between different codes. The aim of this cycle was to develop broader categories or themes that captured the collective participant perceptions of needed learning. Pattern coding was also utilized as part of the second cycle, which involved the identification of emergent themes and the organization of codes into meaningful clusters. Teachers and administrators completed this process by working within their smaller groups and then as one whole group to create themes. Themes, at this stage, were draft competencies teachers and administrators identified as key knowledge, dispositions, or skills they wanted to learn to meet students' learning needs. Each of the seven districts established a set of draft competencies.

A second analysis process was conducted by researchers after each face-to-face session concluded. This round of coding involved a more focused analysis, where similar codes were grouped together, and redundant codes were eliminated (Saldaña, 2016). This was followed by axial coding, where codes were related to each other to form categories. The categories were combined and synthesized to create overarching themes. The language of the themes was refined by researchers to create competencies.

This process was conducted for each district, producing seven individual competency sets applying the language specific to the participants' voice. Focus groups with each district allowed researchers to engage in dialogue with participants around the completed competencies. Two main questions drove the discussions: 1) How do the competencies represent your voice from the design session? 2) What is missing or needs clarification? Revisions were completed based on the focus group responses. The final version was shared with the superintendent of each district. Researchers then compared data and themes across districts, looking for overarching patterns and

relationships in the teachers' responses, facilitating a more nuanced understanding of their learning needs and priorities in teaching K-12 students.

The analysis was conducted with a commitment to methodological rigor and reflective consideration, ensuring the credibility, trustworthiness, and authenticity of the findings. Researchers engaged in a member-checking process with each district. Each set of competencies was cross-analyzed to create a comprehensive set of state-level competencies. Reflexivity (Willig, 2013) was practiced throughout the data collection and analysis, with regular reflections and discussions among the research team to ensure transparency and objectivity in the interpretation of the data.

Results

Portrait of an Educator

Each participating district created a unique set of competencies specific to their environment, students, and teachers. The number of competencies each produced varied from four to eight. Table 2 illustrates each's districts distinct profile.

Table 2

District Specific Competencies Represented in each State Competency

Core State Competency	PDist 1 7	PDist 2 6	PDist 3 7	PDist 4 7	PDist 5 6	PDist 6 7	PDist 7 5	State
Model and cultivate learner-centered mindsets	X	X	X	X	X	X	X	X
Design and Implement learner-centered assessments	X		X	X		X		X
Build learner-centered relationships and culture	X	X	X	X	X	X		X
Design and implement learner-centered instruction	X	X	X	X		X		X
Sustain and cultivate wellness	X	X		X	X	X	X	X
Collaborate, communicate, and create learner-centered systems	X	X	X	X	X	X	X	X

Champion learner-centered systems and communities	X	X	X	X	X	X	X	X
Design and implement equitable and inclusive learning environments			X		X		X	X

To honor teacher voice, final drafts of the competencies used exact terminology and phrasing developed by teachers for each competency's specific indicators. Issues that persist across Wyoming are present in several districts' final competencies yet remain unique to the district through the personalized indicators. Researchers compared competencies across districts and developed a comprehensive Portrait of a Wyoming Educator. This state-level model is represented in Figure 1.

Figure 1.

Wyoming Portrait of an Educator

Note: Appendix A includes the detailed state competencies

LXD Principles

To identify how the MECP embodied the principles of LXD, we aligned key components of the program and with specific LXD elements. Table 3 highlights the integration of LXD principles within the MECP, illustrating how each aspect of the program is designed to create a learner-centered, engaging, and impactful professional development experience for rural educators.

Table 3

LXD Principles Visible in the MECP

LXD Principle	MECP Component
Learner-Centered Approach	Co-Creation of Competencies: Involvement of teachers and administrators in designing competencies
	Personalized Learning Paths: Adaptive learning pathways tailored to individual proficiency levels.
Interactive Engaging Content	Multimodal Reflections and Quizzes: Interactive elements to enhance engagement
	Demonstrations of Learning: Practical applications integrated into modules
Authentic Application	Contextual Relevance: Learning experiences applicable to daily classroom activities.
	Scenario-Based Learning: Real-world scenarios to mirror actual classroom situations.
	Demonstrations of Learning: Applied in real-time within participant classrooms
Feedback and Reflection	Embedded Feedback Mechanisms: Continuous feedback from the system and peers
	Reflective Practices: Activities promoting metacognition and self-awareness.
Iterative Design	Continuous Improvement: Regular updates based on participant feedback.
	Pilot Testing and Revisions: Iterative cycle of testing and revising modules
Empathy and Understanding	Design Thinking Principles: Phases like empathize, ideate, and prototype to deeply understand rural educators' challenges and needs.

The results presented highlight the distinct competencies developed by each participating district and their alignment with the overall Wyoming Portrait of an Educator. These competencies, informed by direct input from rural educators, emphasize a learner-centered approach tailored to the unique needs of each district. Moving forward, the discussion will delve into the implications of these findings, exploring how the integration of LXD principles facilitated the creation of adaptive and responsive professional development pathways, and the broader impacts on teacher retention and educational outcomes in rural contexts.

Discussion

Rural educators have their own unique needs, even within districts in the same state. Traditional instructional design techniques for developing online professional development would have failed to address the distinctive needs of districts within a rural state. To address this gap and design education that is truly based on the unique needs of rural educators, we turned to LXD, leveraging its principles to create personalized, competency-based online professional development opportunities. LXD allowed us to anchor our work in an understanding of how

current and future forces are redefining what today's students need to know and be able to do for success in the complex world of tomorrow. The focus groups and dialogue with participants provided rich insights as to the specific needs of each district and its students, allowing customized competencies to emerge.

LXD principles are favored in creating personalized competency-based online professional development opportunities. As a learning design process, "a designer is able to empathize with the learner and discover new possibilities to solve their problems, tackle their challenges, or address their needs" (Floor, 2023, p. 32). The core idea of LXD as a professional development framework is that a designer needs to have empathy for the learner in addition to simply creating content. In the context of developing professional learning modules to address the Wyoming Portrait of an Educator competencies, the LXD framework is visible in the following ways:

Learner-Centered Approach: The competencies that drive the content alignment of the project were co-constructed with the participants, who are representative of the learners who will participate in the professional learning. The learner-centered approach extends to the adaptive features, creating opportunity to gather feedback within the learning process, and creating personalized learning paths among different topics.

Interactive and Engaging Content: The modules include unique content selected to address what participants asked for. Elements such as multimodal reflections and quizzes, adaptive activities, and demonstrations of learning with learner-specific options build interactivity and facilitated active learning.

Real-World Application: The learning experiences are grounded in real-world scenarios and practical applications, enabling participants to see the relevance of the competencies to their daily teaching practice. The demonstration of learning activities for each module are designed to be directly applied in teachers' current classrooms.

Feedback and Reflection: Opportunities for feedback from learners are embedded into the module in both open-ended feedback about content and design, and an adaptive feature guiding the progress of the learner. Feedback is also given for correct/incorrect answers through the module and on the demonstration of learning at the end of each module. Reflection is embedded in each module to promote metacognition and self-awareness of learning progress. This helps participants to assess their progress, identify areas for improvement, and set goals for further development.

Iterative Design: The development of the modules has followed an iterative process with ongoing evaluation and refinement based on feedback on content and interface design. The learning path also intends to support iterative learning, creating opportunities for participants to start at a self-assessed level from novice to expert, yet adjusting based on performance and iterating learning paths to support individual learners' progress.

By using the LXD framework, the online learning modules are being designed to effectively address the individual district's needs and meet the state-level competencies,

providing teachers with meaningful and impactful learning experiences that support their professional growth and development. Through this approach, teachers are afforded meaningful and impactful learning experiences that not only foster their professional growth but also empower them to develop competencies rooted in human experience and educational best practices. In this vital era of teacher retention, giving educators the opportunity to create professional development rooted in what they believe is best for their districts and their students is incredibly powerful. When it comes to developing accessible and customized learning opportunities to support the unique needs of rural education, it is important to meet teachers where they are.

Integrating LXD principles was influential in designing adaptive and responsive professional development pathways that are finely tuned to the needs of rural educators. By focusing on empathy and co-creation, LXD has ensured that the professional learning opportunities are not only relevant but also engaging and applicable to participants' practice. This approach allows for the customization of content to reflect the specific challenges and contexts of rural teaching, thereby making the professional development more meaningful for the participants. The adaptive nature of these pathways intends for teachers to receive support that evolves with their growing competencies and changing needs, fostering a sense of ownership and investment in their professional growth. This, in turn, has broader implications for teacher retention, as educators who feel supported and valued are more likely to remain in their positions (Shaha & Ellsworth, 2013). Furthermore, the emphasis on practical application and real-world scenarios within the LXD framework enhances educational outcomes by directly translating professional learning into improved classroom practices. Overall, the strategic use of LXD in designing these pathways underscores its potential to address systemic issues in rural education by building a more robust, responsive, and sustainable professional development ecosystem.

Continued Research

While this study provides valuable insights into the collaboration with learners to design competencies relevant to their needs in rural contexts and informs the design of the MECP professional learning modules, further research is needed to comprehensively evaluate its effectiveness and impact on teacher retention. Specifically, extended research could determine the longer-term influence of the professional learning modules on teacher retention rates. This would involve tracking participants' use of MECP modules over time and assessing whether the initial benefits observed are sustained over time.

During implementation of the professional learning modules, researchers can explore the specific elements of the LXD contributing most significantly to adaptability and, potentially, teacher retention. Identifying these components can help refine and enhance the design of MECP and inform future professional learning initiatives. Understanding which aspects are most effective in supporting and retaining teachers will provide valuable guidance for developing more targeted and impactful professional development programs. Additionally, investigating the contextual factors that influence the success of MECP in varied educational settings is crucial. Comparative studies across diverse rural contexts can shed light on how these variables interact and affect outcomes.

It is also important to consider the perspectives of the teachers themselves in future research. They were co-creators in the competencies, which inform the content of the professional learning modules. Their perspectives capture teachers' experiences, challenges, and perceptions of if and how professional learning can support their needs. This type of research can provide deeper insights into the factors that motivate them to stay in the profession. This can lead to the development of more empathetic and responsive professional learning designs that truly meet the needs of educators. While we have made progress through exploring co-construction and applying LXD in building competencies to support rural teachers, more extensive and nuanced research is needed to fully understand and enhance the effectiveness of this type of professional learning programs and what influences they might have on teachers.

Conclusion

This research contributes to teacher education by demonstrating the effectiveness of creating human-centered and competency-based professional learning designed through LXD principles. By involving rural educators in co-constructing the competencies that drive their professional learning, this approach acknowledges and leverages their expertise, leading to more relevant and effective professional development. The iterative and adaptive nature of the LXD framework ensures that professional learning is responsive to the evolving needs of educators, ultimately enhancing their job satisfaction and retention. Findings highlight the potential for scaling and adapting this approach to other rural contexts, contributing to a broader conversation on addressing teacher attrition and improving educational outcomes in rural communities. By prioritizing the unique needs of rural educators and creating tailored professional development opportunities, this research supports the long-term goal of sustaining and enhancing the quality of education in rural areas.

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Appendix A

Wyoming Portrait of an Educator

Core Competencies	Functional Competencies
Model and Cultivate Learner-Centered Mindsets	Encourage and cultivate solution-focused mindsets to solve real-world challenges and strengthen student engagement Begin by asking students to understand the "why" of learning in order to build deeper engagement in the "what"" Create pathways for all learners to find success where curiosity is nurtured and the whole-child embraced Engage all students in the learning while remaining empathetic to the needs of individual learners
Design and Implement Learner-Centered Assessments	Reflect on data in meaningful ways to personalize the next steps in student learning Know that learners are more than test scores and that through competency-based instruction and assessment, all learners have the opportunity to demonstrate that they have mastered both skills and content knowledge through application, not memorization Design assessments that are reflective of both developmentally-appropriate skills and knowledge that support students in solving novel or authentic problems Value the importance of authentic and actionable feedback that challenges all learners to continue to grow • Engage students in demonstrating their learning by incorporating student voice and choice in assessments
Build Learner-Centered Relationships and Culture	Are brave enough to learn from and with students to help empower student agency Model and build authentic empathetic relationships with students to build a safe and supportive learning environment for all Collaborate with parents, students, and colleagues to support the growth of all learners within their community Use developmentally-responsive classroom management strategies to support the needs of all learners and create a safe, positive learning community

	Recognize that all learners are unique in order to authenticity build empathetic relationships and learning experiences that honor cultural diversity, social diversity, and neurodiversity
Design and Implement Learner-Centered Instruction	Design and implement authentic learning experiences that demonstrate a deep knowledge of individual learners and offer choice and voice, therefore increasing student engagement Design learning experiences that support diverse learners in moving from where they are in their learning to a deeper level of analysis, application, and agency Believe that even a small school can design meaningful and impactful learning experiences anchored in high expectations, providing personalized entry points where all students are capable of high levels of success Design multiple pathways to understanding content and skills that connect the standards to the world outside of schools Intentionally plan differentiated learning experiences that are anchored in high expectations in order to support individualized student growth Understand how to access and use educational technology to support deeper student learning and the expression of knowledge
Sustain and Cultivate Wellness	Recognize that social-emotional wellness skills are influenced into the curriculum, not separate learning, and help to create well-rounded persons able to meaningfully contribute in their communities Model essential life skills and mindsets--including empathy, balance, and stress management--in order to support learners in growing their own self-awareness and healthy lifestyles Possess a deep understanding of the developing social-emotional needs of students in order to nurture and sustain an positive learning environment Know that by focusing on the whole-child, they create the conditions necessary for engaging and lasting learning
Collaborate, Communicate, and Create in a Learner-Centered System	Create spaces and opportunities for all learners to express their ideas by becoming more effective communicators and leaders Design experiences that provide opportunities for learners to build globally-transferable skills--including communication, collaboration,

	self-direction, critical and creative thinking--that they will need to be successful in college, career, and the workforce Intentionally teach students not what to think, but rather how to ask questions and think for themselves Create opportunities for students to collaborate and work across differences to solve complex problems Build strong foundations in literacy across content areas to support obtaining, evaluating, and synthesizing information from a variety of sources Understand that creativity is not just for the arts but helps students to think differently, be better problem solvers, and express themselves in meaningful ways
Champion Learner-Centered Systems and Communities	Demonstrate clear communication and strong engagement with families and the larger community to support all learners Seek opportunities to continuously grow in their own practice and translate this learning into meaningful opportunities to improve student learning Are lifelong learners who are passionate about the subjects they teach and they students they serve Foster and sustain strong collaboration between educators to nurture an environment where continuous learning and shared responsibility for all students is the expectation and not the exception Make connections between the learning in the classroom and the community beyond in order to help learners to better understand themselves and their role in the community
Design and Support Equitable and Inclusive Learning Environments	Embed cultural competency into the learning of content at all levels Focus on advocating for and meeting the needs of linguistically, neurologically, developmentally, and culturally diverse learners

DIGITAL CITIZENSHIP VIA ANALYZING, CREATING, THEN SHARING MESSAGES ON CYBERBULLYING

Sam von Gillern
University of Missouri, USA
svongillern@missouri.edu

Laura Obubo
University of Missouri, USA

Amy Lannin
University of Missouri, USA

Amy Hutchison
University of Alabama, USA

Abstract. Digital citizenship is crucial in our technologically-mediated world, as it supports people in their ability to safely, responsibly, and productively utilize digital tools to engage in and with their communities. While digital citizenship has been examined in the literature in various ways, limited scholarship has focused on connections between cyberbullying and digital citizenship. This case study examines the perspectives of two teachers who had students analyze, create, and then share digital messages on cyberbullying to better understand and address the issue in their community. Results indicate the teachers believed that the process of analyzing, creating, and then sharing digital messages on cyberbullying supported students' digital citizenship, fostered creativity, and was a versatile approach to engaging students in civic issues. Implications are discussed.

Keywords. Digital Citizenship, Cyberbullying, Digital Literacy, Civic Engagement, Educational Case Study

Introduction

Digital citizenship is crucial in our technologically-mediated world, as it supports people in their ability to safely, responsibly, and productively utilize digital tools to engage in and with their communities. The International Society for Technology in Education (ISTE, 2016) has highlighted the importance of digital citizenship making it "digital citizen" as one of seven primary standards for technology in education. While digital citizenship has been examined in the literature in various ways (Choi et al., 2017; Ribble et al., 2004, von Gillern et al., 2024a), limited scholarship has focused on connections between cyberbullying and digital citizenship. This case study examines the perspectives of two teachers who had students analyze, create, and then share digital messages about cyberbullying to better understand and address the issue in their community and, through the process, develop valuable digital citizenship skills.

Literature Review

Scholars have explored the concept of digital citizenship in various ways (Chen et al., 2021; Ribble, 2015; Tapingkae et al., 2020). Choi (2016) conducted a concept analysis of the digital citizenship literature and identified four primary themes: ethics, media and information literacy, participation/engagement, and critical resistance. Ethics is a key theme in the literature and emphasizes safe and responsible behavior with digital technologies and online spaces, including as relates to digital etiquette, law, rights, and responsibilities (Ribble et al. 2004). Ethical issues are also central to the International Society for Technology in Education's (ISTE, 2024) student standard on digital citizenship, including by emphasizing respectful online interactions and engaging in safe and legal behaviors.

Media and information literacy is another key component of the digital citizenship literature (Choi et al., 2017). This perspective is undergirded by the fact that people need media literacy skills to access and utilize digital environments (von Gillern et al., 2024b). Further, media literacy skills allow people to critically evaluate media messages in ways that lead to an informed citizenry who understand civic issues (Mihailidis & Thevenin, 2013). Collectively, media literacy skills relate to and support digital citizenship in that they allow people to fluently navigate digital spaces, learn about civic topics, and contribute to online communities.

Choi (2016) notes that participation and engagement are also key themes in the digital citizenship literature. Mossberger et al. (2007) contend that access to digital tools and environments are crucial for full participation in our modern society. Forms of online participation obviously vary greatly, ranging from diverse activities such as connecting with peers and communities on social media to organizing social petitions and sharing information about a new local business to contacting elected representatives (Choi et al., 2017; Gleason & von Gillern, 2018). Participation and engagement are valued in digital citizenship at least in part because they go beyond utilizing digital tools, keeping oneself safe, and obeying copyright laws and involve active efforts to connect with other people in ways that promote community development and change.

This leads to the final digital citizenship theme identified by Choi (2016): critical resistance. This theme is similar to the theme of participation and engagement, but it has an

explicit focus on taking critical perspectives on societal and social power dynamics that privilege some and marginalize others. For example, Garcia et al. (2021) investigate digital citizenship via critical dialogues about race in online spaces and demonstrate the oppressive online media and discourse that insults and marginalizes people of color. In a different approach to critical resistance and digital citizenship, Lozano-Díaz & Fernández-Prados (2020) investigate how digital citizens can engage in online activism to promote environmental sustainability and justice. Such critical perspectives and research aim to demonstrate opportunities for promoting social justice in ways that empower digital citizens to effectively utilize democratic processes and structures to effect community change (von Gillern et al., 2024c).

Collectively, Choi's (2016) four themes on digital citizenship provide a holistic view that demonstrates the multifaceted nature of digital citizenship and opportunities for teachers and students to safely, effectively, and productively engage in digital spaces to become informed citizens capable of promoting change.

Conceptual Framework

The Analyze, Create, Then Share (ACTS) Framework is a recently developed framework for supporting students' digital citizenship engagement (von Gillern et al., 2022). As the name suggests, ACTS Framework activities involve students analyzing, creating, and then sharing media messages on civic topics in ways that facilitate learning and strive to improve their communities. The ACTS Framework recognizes the synergy the digital literacies (Spires et al., 2019), media literacy (Potter, 2018), and digital citizenship (Ribble, 2015), which collectively illustrate the importance of developing students' abilities to effectively utilize digital technologies (digital literacies) and critically evaluating media messages (media literacy) to become an informed and active citizen in digital environments (digital citizenship). These aspects are, admittedly, not discrete skills or perspectives and recent research has demonstrated their similarities and differences (von Gillern et al., 2024b). Yet, the ACTS Framework recognizes that each of these aspects are crucial for supporting children's ability to effectively navigate and participate in our digitally-mediated world.

Further, strong and capable digital citizens draw upon digital literacies and media literacy to bolster their participation in civic processes. These ideas underpin the ACTS Framework in an effort to empower teachers and students to develop and draw upon their abilities to utilize digital technologies to become well-informed citizens capable of advocating for and enacting change in their communities (von Gillern et al., 2022). This goal is supported by the tripartite structure of the ACTS Framework. Students first utilize digital and media literacy skills to access and analyze resources on civic topics. This allows students to understand critical information, including facts and perspectives, to become informed about the focal issue. Developing their understanding of the civic issue directly feeds their ability to create informative civic messages themselves, a process involving digital and media literacy skills, such as utilizing digital platforms and crafting compelling messages. Finally, the process of sharing one's message requires students to again utilize digital and media literacy skills by identifying and pursuing avenues disseminating their messages. While the analyzing and creating phases promote students' digital citizenship by helping them become informed citizens capable of advocating for

change, the sharing phase transforms what are primarily intellectual exercises into active civic engagement thereby developing students' digital citizenship skills.

Scholarship on digital citizenship has explored the perspectives of researchers and experiences of educators and students in myriad ways, and scholars have recently begun exploring connections between cyberbullying and digital citizenship (Fredrick et al., 2023; Vlaanderen et al., 2020). Cyberbullying involves profound and persistent harassment of individuals mediated by digital technologies and has severe and tragic consequences, including "…low self-esteem, suicidal ideation, anger, frustration, and a variety of other emotional and psychological problems" (Cyberbullying Research Center, n.d.). Scholarship illustrates that raising awareness of cyberbullying and having students reflect on ways to address and mitigate cyberbullying can reduce its presence and impact (Slonje et al., 2013). In response, the present study examines the experiences and perspectives of two teachers who sought to explore the concept of cyberbullying with their students to make a positive impact on their community.

Methods

Study Context and Participants

Given the importance of digital citizenship and the prominence of cyberbullying, this study investigates the perspectives of two teachers from a rural district in the Midwestern United States who had their students utilize the ACTS Framework (von Gillern et al., 2022) to analyze, create, and then share digital messages on cyberbullying. The two participating teachers were Mr. Daniels and Mrs. Jones who taught in Open Plains School District (participant and school district names are pseudonyms). Approximately 50% of students in Open Plains School District qualify for free or reduced lunch, and the student population is approximately 87% white, 4% Hispanic, 4% American Indian, 3% multiracial, and 1% African American. Mr. Daniels was in his 12th year of teaching and Mrs. Jones was in her 2nd year of teaching at the time of the study activity. Mr. Daniels taught the activity to an 8th Grade Media class at Open Plains middle school. My Daniels also taught the activity to two classes at Open Plains High-School, including 9-12th Grade Introduction to Media, which consisted primarily of students in grades 9 and 10, and 9-12th Grade Advanced Media, which consisted mostly of students in grades 11 and 12. Mrs. Jones taught the activity to only her 10-12th Grade Entrepreneurship at Open Plains High-School, which was composed primarily of students in grades 11 and 12. Each class had approximately 15-20 students.

For the ACTS activity, students first explored different digital resources, including resources from StopBullying.gov, Cyberbullying.org, and PACER's National Bullying Prevention Center). Student's then *analyzed* their content for prominent ideas on cyberbullying and methods for mitigation. Drawing upon their analysis, students then *created* digital artifacts, primarily digital posters, that shared important information about cyberbullying to raise awareness and reduce its presence in the community. With the support of teachers, students then *shared* their artifacts with their classmates as well as posted them to school announcement monitors, the school social media page, and the student newspaper.

Data Collection and Analysis

After the ACTS Framework activity on cyberbullying concluded, the two teachers each individually participated in a semi-structured interview with the researcher. Guiding questions for the interview included questions such as:

- What are your thoughts on the ACTS Framework?
- Do you think the ACTS Framework can support students' digital citizenship skills? If so, how?
- If you were to do this unit or a similar unit again using the ACTS Framework, what might you do differently?
- What would you like other teachers to know about the ACTS Framework?

The interviews each lasted approximately 25 minutes in length and were recorded and transcribed. The transcription file was then uploaded to MAXQDA, a qualitative coding software. Process codes (Saldaña, 2021) were applied to the interview data in MAXQDA. Process coding entails applying gerunds (i.e., -ing words) to segments of data to identify key processes related to the following research question. The use of process codes allows researchers to focus on the key activities and actions that underpin the data. The process codes applied to the data included both the gerund as well as a note that provides more specificity about the focal data segment. Sample codes included in this research include "raising (students' awareness)", "enabling (students' creativity)", and "adjusting (framework for usability)". Collectively, process coding allowed the researchers to examine the following research question:

- What are the perspectives of teachers' on utilizing the ACTS Framework to explore the topic of cyberbullying?

After the process codes were applied to the data, the codes were examined by two researchers engaged in a dialogic reliability check (Åkerlind, 2005) to discuss patterns and identify themes related to the research question. This discussion involved two researchers discussing which ideas were most prominent, how to combine codes into themes, and determining which codes were present in, but not central to, the teachers' perspectives and thus not included in the final themes. For example, the codes of "enabling (student creativity)" and "diversifying (modes of communication)" were combined into the theme of "Enabling Student Creativity." Additionally, while "facilitating (peer feedback)" was a code, it was not prominent enough to warrant inclusion in a final theme. Collectively, the dialogic reliability check allowed the researchers to deliberate and decide upon key themes that addressed the research question.

Results

From the data analysis, the researchers identified the primary themes of (1) supporting digital citizenship, (2) enabling student creativity, and (3) versatility in application.

Supporting Digital Citizenship

During the interviews, Mr. Daniels and Mrs. Jones illustrated how the ACTS activity helped students explore resources and reflect on the civic topic of cyberbullying to become more informed about the issue and its consequences. Mr. Daniels noted that cyberbullying "is a big issue for quite a few people…and some of them caught on like, 'oh, yeah, like we've probably done this, or we've seen this happen.'" He continued, saying, "It was something that they could sink their teeth into, and you know, get some real-world experience with a topic that meant something to them." Mrs. Jones agreed and reflected, "it opened the kids' eyes," and broadened students' understanding of cyberbullying." Mr. Daniels noticed that using the ACTS Framework to explore and address this authentic issue "was a very positive 'we could actually do more as a community together' experience." Collectively, the teachers saw this activity as supporting digital citizenship by becoming informed about the focal issue (i.e., cyberbullying) and thoughtfully creating and sharing messages to raise awareness and effect change in their community. While engaging, analyzing, creating, and then sharing digital messages on any civic issue can support digital citizenship, these teachers and students focused on cyberbullying, which has specific connections to digital citizenship, such as engaging in safe and responsible online behavior.

Enabling Student Creativity

The teachers also appreciated how the ACTS activity enabled students to be creative in their production of digital artifacts (see Figure 1). While most students created digital posters, others decided to create social media posts and one small group even created an animated .gif file. Mr. Daniels noted that the activity overall involved "having the kids [become] aware of what they're doing first, and then kind of like stepping through and creating their own for like campaign." Mrs. Jones agreed and reflected that the activity "makes [students] break things down, before they just post anything." These processes involved students thoughtfully reflecting on important topics related to the issue and creatively identifying ways to convey messages to raise awareness and mitigate cyberbullying. Mrs. Jones noted that the students produced creative and high-quality products, saying, "I was impressed by what they came up with, and that they actually got something, you know, out of it and made good posters…I was proud of them for what they did." Overall, the teachers felt that the ACTS Framework allowed students to first learn about the focal issue through engaging with different online texts, which could then serve as inspiration for their own artifacts in a process mediated by their own creative goals and talents.

Mrs. Jones and Mr. Daniels appreciated how the versatility of the ACTS Framework, and that while they used it to have students engage with the topic of cyberbullying, they and other teachers could use it for various purposes and contexts. Mrs. Jones noted "teachers...could use it for multiple different [grade] levels and multiple different subject areas." She continued, "I could use it tomorrow if I wanted to. I mean it's very easy to adapt to any type of subject area." Similarly, Mr. Daniels commented that the ACTS Framework is "cross-curricular" and "can be used pretty much across the board. It's not just one discipline; it's an interdisciplinary method." The teachers, overall, appreciated this versatility and thought that the ACTS framework's

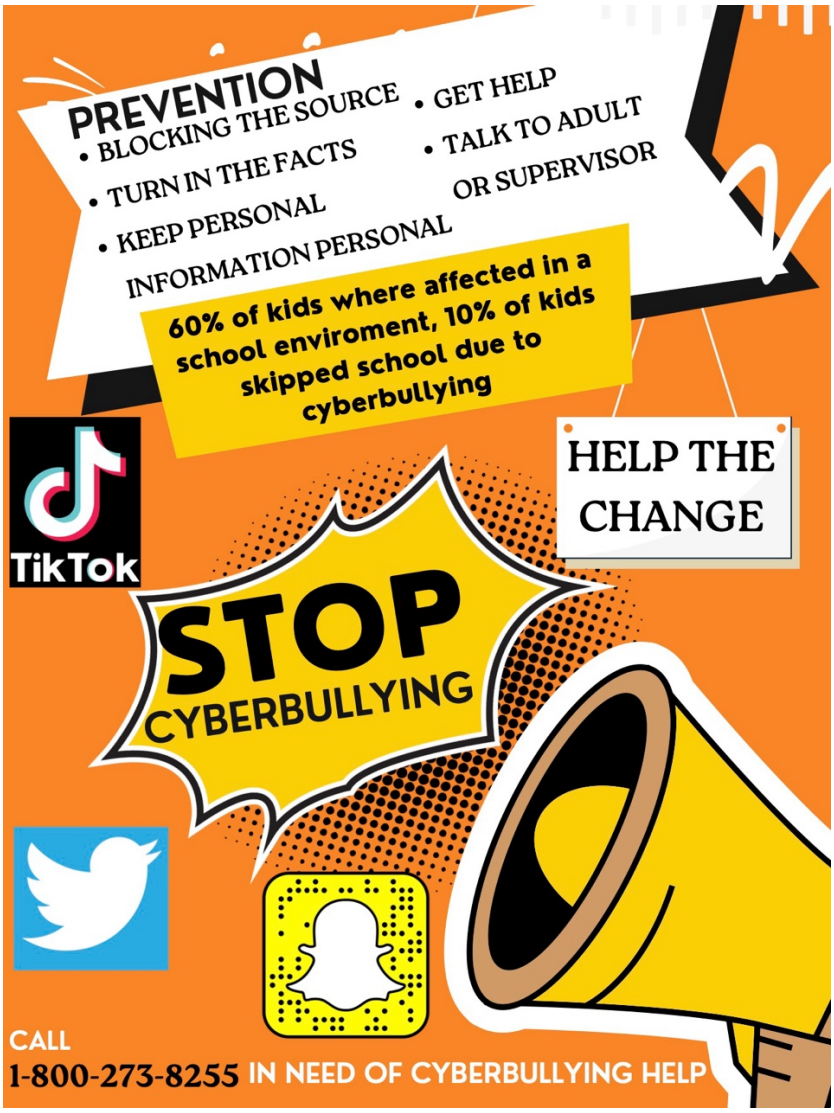
structure, and they found it to be an intuitive and effective approach for helping students engage with important issues in their community.

Discussion

This study illustrates teachers' perspectives on utilizing the ACTS Framework (von Gillern et al., 2022) to support students learning and engagement with the topic of cyberbullying. Results indicate this activity supported students' digital citizenship (Choi et al., 2017) in connection to the civic issue of cyberbullying and contributes to the budding research literature that explores these topics in tandem (Fredrick et al., 2023; Vlaanderen et al., 2020). This study has implications for teaching and teacher education.

Figure 1

Example Student Artifact



Versatility in Application

At a time when all our classrooms and disciplines are faced with the need for multimodal texts, both to read and produce, this lesson and the ACTS framework support students in engaging with and creating their own multimodal texts. Since the ACTS framework was developed with the goal of supporting digital literacies, it was natural that the mode of instruction would involve students in how to read and work with digital texts that were constructed in a variety of modes (e.g., print, visual, audio, video). As students then had the opportunity to choose their preferred mode, they were learning how to communicate in multimodal formats. The research into new literacies supports the use of multimodal text because these "can scaffold children's complex understandings, shed light on their identities as writers, and bring together in school the digital media conventions children experience outside of school" (Leu, et al., 2016, p. 48). Connected to the role of multimodality in learning is the need to support student choice, even if these choices are influenced by teacher guidelines. In this activity on cyberbullying, the topic was provided, but students still had many choices: what to read, what to create, and what message to share. As seen in other studies, students write and create more when they have choices about how to engage in the activity (Lannin et al., 2014).

Lessons with the ACTS Framework can be facilitated across content areas. Social studies education has a long history of supporting students in their understanding of civic issues and mechanisms for facilitating community change (Castro & Knowles, 2017), and the ACTS Framework may support social studies teachers in their work to help students understand social issues and advocate for community improvement. Science teachers may find the framework helpful to not only support students' understanding of socio-scientific issues (Zangori et al., 2017), such as climate change and environmental degradation, but also actively aim to raise awareness of these issues and create plans and programs for their community to actively address such issues. Math teachers may address similar issues but include an explicit focus on statistical data and statistical data. Such efforts, individually and collectively, demonstrate the relevance of digital literacies, media literacy, and digital citizenship across the content areas in ways the support students in their ability to become well-informed and capable citizens.

Conclusion

Ultimately, it is critical for teachers to provide students with opportunities to engage with civic issues relevant to their communities (Choi et al., 2017; Garcia et al., 2021). The ACTS Framework (von Gillern et al., 2022) can serve as a tool for teachers and students in their efforts to holistically examine and participate in civil discourse. Cyberbullying is a prominent issue in the lives of many children (Slonje et al., 2013) and worth examining in the classroom. The literature would benefit from future research that continues to examine cyberbullying, particularly as new technologies that may impact cyberbullying emerge, such as generative artificial intelligence (U.S. Department of Education, 2023). While cyberbullying is obviously a worthy topic for examination, many other civic issues that affect children also deserve scholarly attention in ways that highlight how teachers and students can investigate and advocate for positive change in their communities, and the ACTS Framework can support such efforts.

Limitations

While this study contributes to the digital citizenship and cyberbullying scholarship, it has its limitations. First, it focuses on two teachers. While these teachers provide valuable perspectives, additional research that examines educators' perspectives on the ACTS Framework would help build out scholarship on how the framework can support digital citizenship learning. Second and relatedly, further research that investigates the use of the ACTS Framework in different contexts is needed. The present study focused on a rural Midwestern community, and other research that examines how diverse schools can integrate ACTS activities with various civic issues is needed. Finally, examining teachers' perspectives is obviously important, but research that examines students' perspectives on ACTS activities and digital citizenship is also valuable. These issues and directions for future research are important as civic issues are constantly in flux, and the development of new technologies, including artificial intelligence, will shape how teachers and students approach digital and civic communication in the future (von Gillern, 2024a).

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