Exploring the Potential of an Online Suite of Practice-Based Activities for Supporting Preservice Elementary Teachers in Learning How to Facilitate Argumentation-Focused Discussions in Mathematics and Science

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Abstract: This study explored the use of a three-part suite of practice-based activities -- one- and two-player online simulations, an avatar-based simulation, and a virtual teaching simulator—for supporting preservice teachers in learning how to facilitate argumentation-focused discussions in elementary mathematics and science. We share findings from analysis of survey data examining four elementary teacher educators' perceptions about using these activities within their respective elementary methods courses. Findings suggest the teacher educators perceived the activities as supporting their preservice teachers' learning and reinforced the need for teacher educators to have adequate time to prepare for integrating these activities into teacher education courses.

Introduction/Study Context

In mathematics and science education, engaging students in argumentation in which they can construct, justify, and critique ideas as they work towards more robust mathematical or scientific understanding is an important aspect of high-quality instruction (Osborne, 2012; Staples et al., 2016). Research suggests that one productive approach for providing such learning experiences for students is to engage them in argumentation-focused discussions

(Chinn & Osborne, 2010; Makar et al., 2015). Yet, learning how to facilitate such discussions requires scaffolded and targeted learning opportunities to build teachers' knowledge, skills, and abilities. In this study, we explored the use of a novel and innovative technology-based system for supporting preservice teachers (PSTs) in learning how to facilitate argumentation-focused discussions in elementary mathematics and science. This system included an online suite (what we refer to as the online practice suite or OPS) of practice-based activities that was piloted within elementary mathematics and science methods courses. These activities included one- and two-player online simulations, an avatar-based simulation, and a virtual teaching simulator where PSTs could practice the skills required to facilitate argumentation-focused discussions. In this manuscript, we describe the design of the OPS activities and explain how they were constructed to scaffold PSTs' learning of this ambitious teaching practice. We also share findings from our analysis of survey data collected during our elementary pilot to address the following research questions (RQs):

- RQ1: What are teacher educators' (TEs') perceptions regarding what the PSTs learned from engaging in the OPS activities?
- RQ2: What are TEs' perceptions about the usefulness of and impediments to integrating OPS activities into teacher education courses?

Framework

This research study is grounded in a theory of practice-based teacher education, which posits that teacher learning occurs through opportunities for teachers to consider, engage in, and reflect on the practice-based work of teaching (Grossman, Hammernesset al., 2009; Grossman, 2018). Central to this theoretical framing is the idea that PSTs' learning should be linked directly to classroom practice (Forzani, 2014) as they learn to engage in the interactive work of teaching within specific content areas (Ball & Forzani, 2009). Within teacher education programs, Grossman, Hammerness, et al. (2009) advocated that TEs use various pedagogies of practice, such as representations of practice, decompositions of practice, and approximations of practice, to support PSTs' development (Francis et al., 2017). Examples of these pedagogies include, respectively, having PSTs: analyze students' written work or written cases of instructional situations, identify the critical components of a teaching practice through observing videos of instruction, and conduct clinical interviews with individual students to elicit their thinking or practice facilitating a discussion with small groups of students in a virtual classroom. Of note, Grossman, Compton, et al. (2009) also illustrate approximations as falling along a continuum of authenticity, with approximations that focus on fewer facets of practice on one end and approximations that occur in real time with multiple complex demands to manage falling on the other (p. 2079). This suggests a natural scaffolding that we have capitalized on in the OPS project where PSTs undertake a series of online teaching simulations linked with respect to content but progressively building in terms of complexity and authenticity. Organizing PSTs' learning around such opportunities provides a way for them to develop the knowledge, skills, and dispositions they need to become successful practitioners in their own classrooms; providing such opportunities within teacher education also requires TEs to make important conceptual and practical changes in the pedagogies used to support this work (DeGraff et al., 2015; Kavanagh et al., 2020; McDonald et al., 2013; Peercy & Troyan, 2017; Tyminski et al., 2014). One of these pedagogies – approximations of practice – is the primary focus of this study, as each of the OPS activities is designed to engage PSTs in an approximation of some component of the work of teaching.

Literature Review

In teacher education, peer rehearsals are one commonly used approach to engage PSTs in approximations of practice where PSTs practice teaching a lesson or part of a lesson to each other – one PST acts as the teacher while the other PSTs act as K-12 students. Such rehearsals have been shown to develop PSTs' instructional practice, knowledge, and dispositions (Anthony et al., 2015; Benedict-Chambers et al., 2020; Ghousseini, 2017). More recently, technological advances have led to other possibilities – most notably the development and use of digitally simulated teaching experiences (Mikeska et al., 2021). These types of digital simulations can involve PSTs in providing written or oral responses to problems of teaching practice or interacting with human-in-the-loop digital simulations where one or more live actors play the role of digital avatars in real time, although the live actor's identity is hidden from the PST. In many ways digital simulations mirror rehearsals and role playing; digital interfaces can allow PSTs to role play with one another anonymously, and that anonymity may support PSTs in engaging more deeply as it may feel more as though they are interacting with students (Straub, 2018). Another difference is that because the identity is concealed, it is possible to engineer the experience such that a trained actor can participate, which can make it easier to control the way that the interaction unfolds. And finally, interaction via a digital interface facilitates the generation of artifacts such as video or transcript records that provide a natural basis for reflection and follow up.

Digital simulations have been touted for their ability to provide teachers with a risk-free environment where they can practice the complex work of teaching, learn from their mistakes, and target specific teaching skills (Billingsley et al., 2019; Dieker et al., 2014). Others have advocated for the use of digital simulated teaching experiences due to the flexibility of customizing the PSTs' learning opportunities and standardizing such experiences (Howell & Mikeska, 2021). The design and use of digital simulations have spanned content areas, teacher populations, grade levels, and purposes, although integrating the use of digital simulations into mathematics and science teacher education is a more recent trend in the field (Mikeska et al., 2021). This gap suggests there is a need to better understand the potential affordances and challenges TEs experience when using such tools in teacher education settings within the content areas. Our study addresses this gap by examining how an OPS comprised of multiple online teaching simulations can be used to help PSTs learn how to engage in one core teaching practice -- facilitating argumentation-focused discussions.

Student learning standards in the United States emphasize the importance of ensuring that students engage in argumentation to develop their conceptual understanding of mathematics and science concepts (National Governors Association, 2010; NGSS Lead States, 2013). In both content areas, successful engagement in argumentation requires that students have opportunities to share and defend their ideas, offer counter arguments and rebuttals, critique each other's ideas, and build towards consensus as ideas are refined and revised (Colley & Windschitl, 2016; Staples et al., 2016). Research has shown that students can learn how to engage in productive argumentation when they have opportunities to engage in discussions (Staples & Newton, 2016; Walshaw & Anthony, 2008). Being able to facilitate productive discussions has been nominated as one of the core teaching practices essential for teachers to learn how to do well (Grossman, 2018), although research has suggested that teachers need support in learning how to engage in this core teaching practice (Davis et al., 2019; Kosko et al., 2014).

Methodology

Sample

Participants in this study included four TEs across three public institutions of higher education (see Table 1). At the start of the study, all TEs indicated that PSTs enrolled in their methods courses had rarely or never studied the importance of discussion prior to the course in which the OPS was being implemented. Three TEs reported that they often focused on teaching PSTs about facilitating discussions in their methods course prior to their participation in this study.

TE ID	TE Role	Identified Race	University Setting	Content Focus	Number of Years Teaching PSTs	Experience Using Simulated Classrooms	Highest Degree Obtained
TE01	Professor	White	Suburban	Science	>10 years	Often	Doctoral degree
TE02	Professor	White	Urban	Science	>10 years	Rarely	Doctoral degree
TE03	Lecturer	White and African American	Suburban	Math	>10 years	Never	Master's degree
TE04	Professor	White	Urban	Math	4-10 years	Never	Doctoral degree

Table 1. Demographics and Prior Experiences Among Teacher Educator Participants

Description of the OPS Activities

Our team created two versions of the OPS – one for elementary mathematics and the other for elementary science. Each OPS is comprised of three practice-based activities: (1) one and two-player online simulations called “focused practice spaces”, (2) an avatar-based simulation, and (3) a virtual teaching simulator. All OPS activities are aligned with respect to two criteria. First, all activities are focused on supporting PSTs in learning how to engage in one core teaching practice -- facilitating argumentation-focused discussions – and designed to address the same dimensions, or features, of that teaching competency (Mikeska et al., 2019; see Table 2). Second, all three OPS activities focus on similar high-leverage mathematics or science content topics. For example, the elementary mathematics OPS activities focus on facilitating discussions around comparing fractions while the elementary science OPS activities address facilitating discussions about conservation of matter.

The three OPS activities are also designed to scaffold PSTs’ learning in multiple ways. First, the OPS activities are designed to begin with a focus on individual skills using the focus practice spaces. Throughout the course of the semester, the simulations move towards engaging the PSTs in learning opportunities where they coordinate the full set of skills required to facilitate argumentation-focused discussions – initially in a small group discussion via the avatar-based simulation to then a whole group discussion in the virtual teaching simulator. Second, the OPS activities start with engaging PSTs in focused, one-on-one interactions with one or two students to opportunities to engage in more extended interactions with small groups and then whole groups of students where they consider multiple students’ ideas and how to support students in interacting across those ideas. The move across the OPS activities from focusing on individual skills to a more complex assemblage of skills supports purposeful scaffolding in terms of the complexity of the work of teaching, which we hypothesize will support PST learning of this core teaching practice. This idea of reducing and then incrementally increasing the complexity in these approximations aligns with other recommendations for developing PSTs’ adaptive expertise (Janssen et al., 2015) The following sections provide a brief overview of each practice-based activity, including an explanation of its goal and how the PSTs engage in the activity, and describe the specific activities designed and used in the elementary mathematics OPS and the elementary science OPS for this study.

Dimension	Brief Description
Dimension 1: Attending to Students’ Ideas	Teachers elicit meaningful contributions from all students and make use of ideas students provide in an effort to make progress toward the learning goal.
Dimension 2: Facilitating a Coherent and Connected Discussion	Teachers support students throughout the discussion to make connections to the content and to the practice of argumentation; using students’ ideas, teachers craft a storyline that is clear to students.
Dimension 3: Encouraging Student-to-Student Interactions	Teachers encourage students to share ideas directly with one another and to build upon each other’s contributions; through these interactions, students should carry the intellectual load.
Dimension 4: Developing Students’ Conceptual Understanding	Teachers support students to engage in sense making about their own and others’ ideas, including developing and incorrect ones, in an effort to build conceptual understanding.
Dimension 5: Engaging Students in Argumentation	Teachers promote argumentation among students by encouraging them to make claims, support them with evidence and reasoning, and to critique and evaluate one another’s arguments.

Table 2. Key Dimensions of Facilitating High-quality, Argumentation-focused Discussions

Focused Practice Spaces

There were two focused practice spaces (FPS) in the elementary OPS: Eliciting Learner Knowledge (ELK) and Teacher Moments. ELK is a simulation where pairs of PSTs role play either a student or a teacher and engage in a text-based chat (Wang et al., 2021). For this project, we developed ELK scenarios where one PST played the role of a teacher and the other played the role of a student with a developing but incomplete understanding of a science or mathematics concept. The two players interacted in ELK during a seven-minute text-based chat. The PST roleplaying the student was charged with accurately representing the understanding of a student, informed by an online profile characterizing the students’ ideas. The goal of the PST playing the teacher was to elicit this student’s understanding of the topic. In the elementary science ELK task, the PSTs role played one of two student profiles, each representing a different student idea about whether and why the amount of matter is conserved in different situations (e.g., when a bottle of water is frozen). In the elementary mathematics ELK task, PSTs role played one of two student profiles; each profile used a different strategy to find fractions in between two given fractions. The PSTs completed several rounds of ELK in class.

Teacher Moments immerses PSTs in vignettes of classroom life and calls upon them to respond spontaneously by either typing or speaking a response (Thompson et al., 2019). For this study, the Teacher Moments simulation focused on looking at students' written work to prepare for an argumentation-based discussion. The storyline for Teacher Moments is that both students from ELK have been paired together for an argumentation-based discussion during class. The teacher notices that neither one of the students are speaking to the other. During Teacher Moments, the PST acts as the teacher and reviews the students' written work before class. The PST prepares prompts about how the students could compare and critique each other's work to help the students start the discussion the following day. In the mathematics Teacher Moments task, PSTs were given both student's solution to the "Fractions Between" problem and the students' comments on whether their partner's written work was a good problem-solving strategy. In the science Teacher Moments task, PSTs were given both students' observations and comments on whether matter was conserved in different situations. The PSTs completed the Teacher Moments simulation for homework and discussed it during class.

Avatar-Based Simulation

In the avatar-based simulation (ABS), PSTs practiced facilitating a small group discussion with five student avatars around a mathematics or science task through the Mursion® portal's virtual classroom (see Figure 1). The 20-minute discussions were video recorded so that each PST and their TE could review the performance, reflect on it, and learn from the experience. A single simulation specialist, or actor, acted as the five student avatars, following semi-structured scripts based on what the PSTs in the discussion said. In the elementary science ABS task, the PSTs facilitated a discussion where the student avatars were asked to construct a consensus argument on whether the amount of matter changed when water, lemon juice and sugar were mixed together to make lemonade. In the elementary mathematics ABS task, the PSTs facilitated a discussion about whether: (a) one strategy for finding fractions between 2/3 and 7/8 works, (b) this strategy would work for other pairs of fractions, and (c) they should keep this strategy in their toolbox for future use. The ABS written tasks included information about what the students completed in class prior to the discussion and written responses from the students and were provided to the PSTs one week in advance of their ABS session to use for planning.

Figure 1. Preservice Teacher Interacting with Student Avatars in the Simulated Classroom. Image courtesy of Mursion®, Inc.

Virtual Teaching Simulator

The virtual teaching simulator (VTS) was designed to provide PSTs with a space where they could practice their instruction in a virtual space that is meant to closely resemble an elementary classroom with 24 student avatars (see portion of classroom in Figure 2). Each PST selected a teacher avatar to represent them in the classroom and then entered the virtual space. Four actors each played two students (eight students in total at two tables); the other 16 students were not interactive. The PST’s goal was to initiate small group discussions to monitor students' comments and ask probing questions. The PST would then decide how to select and sequence the students’ comments to engage the ‘whole class’ (the two groups of four students each) in a consensus-making discussion. Actors were given profiles for each character they played. Each VTS discussion lasted approximately 30 minutes. In the elementary science VTS task, the PSTs facilitated a discussion with the goal of having the students ‘construct an argument, using prior knowledge, evidence and reasoning, about whether the amount of matter changes’ when ice cubes melt in a pitcher of fruit punch. In the elementary mathematics VTS task, the PSTs facilitated a discussion where they engaged students in discussion around the mathematical reasoning that they use to justify their arguments about the task of finding fractions. The PSTs received the written VTS task about a week prior to their session. The task included a general task description, a VTS classroom overview and technical instructions to get started, lesson information and materials (e.g., lab sheet), work samples for each student group, a summary of students’ thinking, and some general guidance on facilitating argumentation-focused discussions.

Figure 2. Teacher Avatar and Student Avatars in the Virtual Teaching Simulator

Data Sources and Collection

Each TE integrated the OPS activities into their elementary mathematics or science methods course (two teacher educators per content area) during the Spring 2021 semester. For each OPS activity, the TEs helped the PSTs prepare for their engagement in the activity and facilitated a debrief/reflection after the PSTs engaged in the practice-based activity. This three-part micro cycle—preparation, engagement in the OPS activity, and debrief/reflection—occurred for each OPS activity. Following each micro cycle, each TE responded to an online survey reporting on their perceptions about the preparation for, engagement in, and debrief/reflection on the specific OPS activity. They also provided written responses about their understanding of discussion and argumentation, their perceptions on what PSTs learned from engaging in the OPS activities, and whether and why they would or would not recommend using the OPS activities in teacher education courses. We focus our analysis of TEs’ responses to three survey questions. One question asked about what they thought the “big takeaways” were that their PSTs learned from engaging in that OPS activity. The second question asked about whether they would recommend using the OPS activity in a future course and to explain their recommendation. The third question asked them to describe any impediments they saw with incorporating the OPS activity into a future course.

Data Analysis

This study used qualitative research methodology (Boyatzis, 1998) to interpret and make sense of the TEs’ open-ended responses to the survey questions about their perceptions of what the PSTs learned from participating in these OPS activities and the usefulness of and impediments to incorporating the OPS activities within teacher education courses. Our team used thematic analysis (Braun & Clark, 2006) to identify patterns or trends in the TEs’ perceptions of PST learning, usefulness, and impediments. The thematic analysis involved reading and rereading across the TEs’ survey responses, identifying and recording the key ideas within their responses for each OPS activity by TE, comparing and contrasting across TEs and OPS activities, and then generating themes across their responses to indicate their overall perceptions within these different components.

Results

RQ1: Perceptions of PST Learning

Two key themes emerged in terms of TEs' perceptions of what the PSTs learned from participating in these OPS activities. The first related to learning about specific instructional moves and the second related to developing a clearer understanding of what preparing to lead a discussion demands of a teacher. First, all TEs expressed how the OPS activities supported the PSTs in learning about and improving their ability to attend to specific instructional features critical to facilitating high-quality, argumentation-focused discussions. Specific instructional moves PSTs learned about included having students construct reasoned arguments, prompting students to engage in direct peer interaction and critique each other's ideas, attending to and making connections between students' ideas, asking higher order questions, letting students lead the discussion, and asking students to justify their thinking through the use of evidence.

During the FPS micro cycle, three TEs engaged their PSTs in analyzing the transcripts from their engagement in the two-player ELK simulation and in writing reflections based on their analysis of the teaching moves they used. TE04 mentioned that through the FPS micro cycle her PSTs learned the "importance of valuing student ideas and eliciting them without providing evaluative comments or funneling them to a correct answer" and were "developing their understanding of the importance of student-to-student talk and argumentation in a discussion." Similarly, after the FPS micro cycle, TE01 explained that her PSTs were able to successfully "…differentiate between open- and closed-ended questions….begin to practice how to elicit claims and evidence-based reasoning from students…begin to generate talk moves to encourage students to share ideas with one another and critique each other's ideas."

Similar ideas were shared by the TEs following the other two micro cycles. For example, TE02 noted how the ABS micro cycle helped her PSTs in learning how to "to attend to students' ideas, make connections, and encourage students to critique ideas." TE01 shared that the small group ABS discussion helped build her PSTs' knowledge on "how to structure a discussion with a launch, organized discussion, and conclusion." Likewise, after the VTS micro cycle, these TEs explained how that OPS activity helped the PSTs learn how to "encourage student to student talk and bridge between the connections they were making to past investigations and the Fruit Punch investigation" (TE02), "transition from small-group monitoring/discussions to a discussion with the whole class" (TE01), and "recognize they needed to ask students for evidence of their thinking" (TE03).

The second theme focused on the TEs' takeaway related to the PSTs' preparation. Most PSTs in this study had limited prior opportunities to observe, much less try out, facilitation of argumentation-focused discussions in these content areas. The TEs noted how engaging in the OPS activities supported the PSTs in understanding the importance of adequately preparing for facilitating these kinds of discussions. For example, after the ABS micro cycle, TE03 explained that her "PSTs learned that preparation for teaching involves not only planning questions but anticipating students' responses" and "learned the importance of involving all students in contributing to class discussions by attending to students' ideas." Similarly, following the VTS micro cycle, the same TE shared that: "The PSTs' reflections indicate that preparing in advance is very important" as was "letting students lead the discussion, asking higher order questions, and attending to students' ideas." While proceedings paper length limitations preclude reporting on the findings from the PSTs' perceptions about the use of the OPS, many PSTs also noted that the OPS helped them develop an understanding of the importance of and strategies to adequately prepare to facilitate these kinds of discussions.

RQ2: Usefulness of and Impediments to Integrating the OPS in Teacher Education Courses

The four TEs expressed strong support for integrating these OPS activities into elementary mathematics and science methods courses. For all three OPS activities, all four TEs selected "yes" to the question about whether they would recommend including each activity into a future section of their methods course. Findings indicated three main themes regarding their positive recommendations for future use of such practice-based activities within teacher education settings. First, all TEs consistently noted that these OPS activities provided opportunities for the PSTs to practice specific teaching or discussions skills. For example, TE01 expressed that the FPS micro cycle created "opportunities for targeted practice in eliciting student knowledge and in preparing to facilitate argumentation discussions between students." Similarly, TE02 explained that her "PSTs definitely need to practice leading coherent and connected discussions. This is something they frequently struggle with and fall right back into the IRE [initiate, respond, and evaluate] pattern of discussions.” Second, these TEs explained how integrating the OPS activities into such courses provided opportunities for substantive reflection on instruction. For example, after the VTS micro cycle, TE03 explained that “…there is a recording and a transcript which allows for reflection” while TE04 noted that the PSTs “were able to get the feel of what it's like to lead a discussion and reflect on it.” Third, the TEs explained that these OPS activities provided a low-risk environment where the PSTs could practice their newly emerging teaching skills without any risk of harm to real students. One example of this theme was shared by TE01 following the ABS micro cycle: “This is one tool that offers unique experiences for PSTs - the ability to focus on the argumentation discussion w/o [without] distractions and w/o [without] fear of ‘harming’ the learning process for real students.” TE02 shared a similar sentiment following the VTS micro cycle, reflecting the first and third themes: “I think it’s always a great learning experience to try out new pedagogical moves in a low stakes environment before working with real children.”

In terms of key impediments to the future use of the OPS activities within teacher education courses, three main themes emerged. First, all TEs noted that the time required for preparation and implementation of the OPS activities was substantial, especially due to the challenge of figuring out how to integrate such activities into an already full course agenda and syllabus and figuring out how to schedule each PST for their OPS enactment sessions. As TE04 noted, “you really need to devote a large portion of your class to it.” Second, the cost associated with using these technology-rich activities, which was covered by the grant but would not be for future use, was perceived as an impediment to future use, especially for the two OPS activities that involved a simulated classroom with trained actors playing the role of the students. Both the ABS and VTS activities require the use of at least one human-in-the-loop to play the role of the student avatars; in addition, the ABS technology requires a license to use and access the simulated classroom technology. For example, TE03 noted that regarding the current form of VTS the “cost of hiring actors for all of the PSTs enrolled in methods courses would be challenging.” TE01’s comment after the VTS micro cycle captured the first two themes succinctly: “Time and money. Time to prepare for, enact, and deliver the experience, and money/resources to support all the folks who are involved in making it possible.” Finally, the TEs noted the importance of ensuring that these online systems are easy to use and how technical challenges, some of which they experienced, would be impediments to future use. For example, while appreciative of the technical support our research team provided, TE01 also noted that one impediment would be “… technical challenges. It was very helpful to have [OPS staff member] present during ELK, but what if she weren't available...”

Discussion and Implications

While we report here only on pilot findings, this study provides early proof of concept of the perceived value of using a scaffolded set of practice-based activities oriented around a common teaching practice, an approach that has not, to our knowledge, been implemented previously. Despite the early, exploratory nature of the work, all participating TEs reported clear value from using the OPS and were able to articulate clear, specific, and meaningful learning that they perceived their PSTs derived from participation.

Collectively, findings point to the productive possibilities for the use of the OPS within teacher education settings. Based on the TEs’ perspectives, integrating the OPS into their elementary mathematics or science methods course afforded many benefits. The most notable ones included helping PSTs develop their knowledge and ability of specific strategies they could use to engage students productively in argumentation-focused discussions and in developing PSTs’ awareness and understanding about the importance of preparing adequately to facilitate such discussions. Successful implementation of the OPS also suggests that, in bringing together different technological approaches, we were able to create a meaningful and cohesive whole that supports PST learning in ways that may go beyond what each of the component activities alone could have provided.

Results from this study also suggest that TEs would welcome the innovative use of these OPS activities in order to provide low-risk practice spaces for PSTs to try out and refine complex instructional practices. Findings also suggest the importance of addressing some of the key impediments that may serve as possible deterrents to access and productive use of such tools for future use by other TEs, such as access to the online simulations and the cost for facilitating interactions in some of the online simulations. Future work in this space suggests the importance of ensuring that TEs have adequate time to prepare for integrating these practice-based activities into teacher education courses and are supported in accessing and using these tools with minimal technical challenges. It would also be important to conduct similar research with a wider variety of TEs, as the current elementary pilot study was limited to a small sample size.

References

Anthony, G., Hunter, J., & Hunter, R. (2015). Supporting prospective teachers to notice students' mathematical thinking through rehearsal activities. *Mathematics Teacher Education & Development, 17*(2), 7-24.

Ball, D. L., & Forzani, F. M. (2009). The work of teaching and the challenge for teacher education. *Journal of Teacher Education, 60*(5), 497-511.

Benedict-Chambers, A., Fick, S. J., & Arias, A. M. (2020). Preservice teachers' noticing of instances for revision during rehearsals: A comparison across three university contexts. *Journal of Science Teacher Education, 31*(4), 435-459.

Billingsley, G., Smith, S., Smith, S., & Meritt, J. (2019). A systematic literature review of using immersive virtual reality technology in teacher education. *Journal of Interactive Learning Research, 30*(1), 65-90.

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development*. Sage.

Braun, V., Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Chin, C., & Osborne, J. (2010). Students' questions and discursive interaction: Their impact on argumentation during collaborative group discussions in science. *Journal of research in Science Teaching*, *47*(7), 883-908.

Colley, C., & Windschitl, M. (2016). Rigor in elementary science students’ discourse: The role of responsiveness and supportive conditions for talk. *Science Education, 100*(6), 1009-1038.

Davis, E. A., Kloser, M., Wells, A., Windschitl, M., Carlson, J., & Marino, J.-C. (2017). Teaching the practice of leading sense-making discussions in science: Science teacher educators using rehearsals. *Journal of Science Teacher Education, 28*(3), 275-293.

DeGraff, T. L., Schmidt, C. M., & Waddell, J. H. (2015). Field-based teacher education in literacy: Preparing teachers in real classroom contexts. *Teaching Education*, *26*(4), 366-382.

Dieker, L. A., Straub, C. L., Hughes, C. E., Hynes, M. C., & Hardin, S. (2014). Learning from virtual students. *Educational Leadership*, *71*(8), 54-58.

Forzani, F. M. (2014). Understanding “core practices” and “practice-based” teacher education: Learning from the past. *Journal of Teacher Education*, *65*(4), 357-368.

Francis, A. T., Olson, M., Weinberg, P. J., & Sterns-Pfeiffer, A. (2018). Not just for novices: The programmatic impact of practice-based teacher education. *Action in Teacher Education*, *40*(2), 119-132.

Ghousseini, H. (2017). Rehearsals of teaching and opportunities to learn mathematical knowledge for teaching. *Cognition and Instruction, 35*(3), 188–211.

Grossman, P. L. (2018). *Teaching core practices in teacher education*. Harvard Education Press.

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. W. (2009). Teaching practice: A cross-professional perspective. *Teachers college record*, *111*(9), 2055-2100.

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and Teaching: Theory and Practice, 15*(2), 273-289.

Howell, H. & Mikeska, J. N. (2021). Approximations of practice as a framework for understanding the role of authenticity in simulations of teaching. *Journal of Research on Technology in Education, 53*(1), 8-20.

Janssen, F., Grossman, P., & Westbroek, H. (2015). Facilitating decomposition and recomposition in practice-based teacher education: The power of modularity. *Teaching and Teacher Education*, *51*, 137-146.

Kavanagh, S. S., Metz, M., Hauser, M., Fogo, B., Taylor, M. W., & Carlson, J. (2020). Practicing responsiveness: Using approximations of teaching to develop teachers’ responsiveness to students’ ideas. *Journal of Teacher Education*, *71*(1), 94-107.

Kosko, K. W., Rougee, A., & Herbst, P. (2014). What actions do teachers envision when asked to facilitate mathematical argumentation in the classroom?. *Mathematics Education Research Journal*, *26*(3), 459-476.

Makar, K., Bakker, A., & Ben-Zvi, D. (2015). Scaffolding norms of argumentation-based inquiry in a primary mathematics classroom. *ZDM*, *47*(7), 1107-1120.

McDonald, M., Kazemi, E., & Kavanagh, S. S. (2013). Core practices and pedagogies of teacher education: A call for a common language and collective activity. *Journal of Teacher Education, 64*(5), 378-386.

Mikeska, J.N., Howell, H., & Straub, C. (2019). Using performance tasks within simulated environments to assess teachers' ability to engage in coordinated, accumulated, and dynamic (CAD) competencies. *International Journal of Testing, 19*(2), 128-147.

Mikeska, J. N., Howell, H., Dieker, L., & Hynes, M. (2021). Understanding the role of simulations in K-12 mathematics and science teacher education: Outcomes from a teacher education simulation conference. *Contemporary Issues in Technology and Teacher Education*, *21*(3).

National Governors Association Center for Best Practices, Council of Chief State School Officers (2010). *Common Core State Standards* (Mathematics). National Governors Association Center for Best Practices, Council of Chief State School Officers, Washington D.C.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Osborne, J. (2012). The role of argument: Learning how to learn in school science. In *Second international handbook of science education* (pp. 933-949). Springer, Dordrecht.

Peercy, M. M., & Troyan, F. J. (2017). Making transparent the challenges of developing a practice-based pedagogy of teacher education. *Teaching and Teacher Education*, *61*, 26-36.

Staples, M., & Newton, J. (2016). Teachers' contextualization of argumentation in the mathematics classroom. *Theory into Practice*, *55*(4), 294-301.

Staples, M., Newton, J., Kosko, K., Conner, A., Cirillo, M., & Bieda, K. (2016). Conceptions and consequences of what we call argumentation, justification, and proof. In *Proceedings of the 38th conference of the North-American chapter of the international group for the psychology of mathematics education* (pp. 1704-1712). Tuscon: PME-NA.

Straub, C. (2018). *Best in class leadership development: How virtual reality and avatars are changing the learning landscape*. San Francisco: Mursion, Inc.

Thompson, M., Owho-Ovuakporie, K., Robinson, K., Kim, Y. J., Slama, R., & Reich, J. (2019). Teacher Moments: A digital simulation for preservice teachers to approximate parent–teacher conversations. *Journal of Digital Learning in Teacher Education*, *35*(3), 144-164.

Tyminski, A. M., Zambak, V. S., Drake, C., & Land, T. J. (2014). Using representations, decomposition, and approximations of practices to support prospective elementary mathematics teachers' practice of organizing discussions. *Journal of Mathematics Teacher Education*, *17*(5), 463-487.

Walshaw, M. & Anthony, G. (2008). The teacher's role in classroom discourse: A review of recent research into mathematics classrooms. *Review of Educational Research, 78*, 516-551.

Wang, X., Thompson, M., Yang, K., Roy, D., Koedinger, K.R., Rose, C.P., & Reich, J. (2021). Practice-based teacher questioning strategy with ELK: A role-playing simulation for eliciting learner knowledge. *Proceedings of the ACM on Human-Computer Interaction, 5*(CSCW1), 1-27.

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