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Understanding the Role of Simulations in K-12 Mathematics and Science Teacher Education: Outcomes From a Teacher Education Simulation Conference

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This article reports outcomes from a working conference focused on the role of simulations in K-12 mathematics and science teacher education. The authors synthesized work shared via conference papers and presentations organized around three questions: (a) How are simulations defined and used? (b) How do simulations work? and (c) What evidence is being collected and what evidence should be collected about the use of simulations to prepare K-12 mathematics and science teachers? Results suggested that, while simulations vary in terms of format and foci, one common element is that they serve as responsive and interactive learning spaces where preservice and in-service teachers can rehearse critical instructional practices essential to the work of teaching in these disciplines. Attendees noted the importance of learning cycles to achieve the full benefit of these simulations to promote teachers' learning and advocated for using experimental and quasi-experimental designs to better understand for whom, under what conditions, and for what purposes simulations are best used to prepare K-12 mathematics and science teachers. Connections to and implications for ongoing work within mathematics and science practice-based teacher education are discussed.

Teaching effectiveness is one of the most important factors related to student learning (Chamberlain, 2013; Chetty et al., 2014; Rivkin et al, 2005; Rockoff, 2004). Yet, learning to teach effectively is a complicated, complex, and arduous process. Research abounds suggesting that learning to teach requires not only helping novices learn the content they will teach, but also requires helping them learn how to achieve productive disciplinary engagement for K-12 students (Ball et al., 2008; Gess-Newsome, 2015; Rockoff et al., 2011; Wilson, 2016).

Opportunities for teachers to practice novel teaching strategies and approaches are one mechanism to prepare effective teachers (Francis et al., 2018; Ghousseini, 2017; Lampert et al., 2013; Masters, 2020). Typically, these practice teaching opportunities occur as part of student teaching or an internship at a local school with K-12 students (Brown et al., 2015; Ronfeldt & Reininger, 2012). However, the increasing focus on practice-based teacher education has suggested other alternatives to preparing teachers. Simulations, either via online, technologically mediated practice spaces or via face-to-face rehearsals, serve as approximations of practice that provide opportunities for teachers to try out new teaching practices prior to stepping into a classroom and to do so in a safe space without the potential of harming real students.

Despite the increasing use of simulations to support teachers' learning in mathematics and science teacher education (Mikeska & Howell, 2020; Straub et al., 2014, 2015), little has been done to examine the breadth of research in this area and the ways in which teacher educators and researchers are addressing questions about the conditions, for whom, and for what purposes simulations are best used to prepare K-12 mathematics and science teachers. Instead, most research in the field has focused on ways technology can be used directly to support K-12 student learning (e.g., Thieman, 2008), ways teachers can build their technology skills for use in K-12 classrooms (e.g., Bond et al., 2020), or frameworks to help teacher educators consider how to support teachers in learning about technology integration into their K-12 classrooms (e.g., Kimmons et al., 2020). Research that has addressed questions about ways technology can support teacher, not student, learning has typically used other technological tools, such as video-based reflections (Sydnor et al., 2020) or game-based professional development (Smith et al., 2020).

Our work directly addressed this important gap in the field by taking on the question of how technology – in this case, simulations – is being used to impact and study teachers' learning. We convened a conference with current scholars working in this area and identified patterns and themes in their perspectives and work related to designing and using simulations to support teacher learning.

The following section describes how we grounded the impetus and need for such a conference within the current literature on practice-based teacher education and the use of simulations. The key research questions addressed in this study are described, along with details about the conference structure and attendees and the methods used to analyze attendees' conference papers and presentation materials. Finally, the key conference outcomes are described, followed by a discussion about promising next steps to address current gaps and capitalize on opportunities for using and studying simulations in mathematics and science teacher education contexts.

Related Literature

Practice-Based Teacher Education

For the last few decades, rigorous student learning standards have been the norm in both mathematics and science education (National Governors Association, 2010; National Research Council, 2013). The student learning standards in mathematics and science, coupled with the increasingly diverse population of students across the nation (Cheuk, 2016; National Center for Education Statistics, 2015), have highlighted the importance of preparing teachers to engage in complex and ambitious teaching practices for all students (Boerst et al., 2011; Horn, 2010; Jackson et al., 2013; Kloser, 2014; Windschitl et al., 2012). "Practice" is used here with respect to student learning to denote content practices as described in the *Next Generation Science Standards* (National Research Council, 2013) and *Common Core State Standards* **(**National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), which make up part of the core content students are expected to learn. In contrast, "teaching practices" are the actions teachers engage in that support student learning, and "practice-based" teacher education is a movement centered on engaging novice teachers in those teaching practices.

Despite these rigorous learning standards, teaching practices have failed to shift in similar ways, with approaches remaining relatively impervious to reform efforts on a large scale (Banilower et al., 2018). A critical conundrum facing the field is how to prepare preservice and in-service mathematics and science teachers to engage productively in the complexity of teaching required for addressing these ambitious student learning standards.

One compelling response to this challenge has been the use of practice-based teacher education to prepare mathematics and science teachers. Practice-based models of teacher education involve teachers learning in and from their practice by immersion in the activities they routinely engage in (Ball & Forzani, 2009; Grossman, Hammerness et al., 2009), with some work in this area focused on the teaching of K-12 mathematics and science (Annetta et al., 2014; Benedict-Chambers & Aram, 2017; Chazen & Herbst, 2012; Davis & Boerst, 2014; Davis et al., 2017; Dotger et al., 2014; Straub et al., 2014, 2015; Windschitl et al., 2012). One promising approach is in the use of approximations of practice (Grossman, Compton et al., 2009) to help preservice and in-service mathematics and science teachers learn how to refine their content teaching.

Approximations of practice is a term coined by Grossman, Compton et al. (2009) to describe one important pedagogy used to prepare people for professional practice in various careers. In the context of teacher education, approximations of practice refer to opportunities for teachers to try out and simulate aspects of the work of teaching in a space that is supportive, reduced in complexity, and encouraging of deliberate practice.

Historically, approximations of practice have included role-plays, sometimes referred to as rehearsals, whereby individuals, such as teacher educators, fellow teachers, or trained adults, play the role of K-12 students as prospective teachers of mathematics and science tryout an instructional practice, such as eliciting student ideas or facilitating a small group discussion. “Rehearsal” is the term of choice for a number of projects included in the conference described here, and we generally use the term to denote an activity in which the teacher-in-training has an opportunity to practice teaching a topic in an informal setting, such as teaching content to peers in a methods course, but in which there is considerable leeway in how the teaching plays out [a]. More recently, rapid technological advances have paved the way for digital classroom spaces and tools, such as simulated classrooms comprised of student avatars (Cohen et al., 2020; Mikeska & Howell, 2020) and online lesson sketch instruments (Herbst & Kosko, 2014), as additional avenues for engaging teachers in approximations of practice.

Across these cases, one common thread is the idea that “approximations of practice are not the real thing,” as they involve prospective teachers practicing in a simulated space. They, however, “differ regarding the level of completeness and congruence with which they approximate practice” (Grossman, Compton et al., 2009, p. 2078).

The emphasis in this pedagogical approach on simulating practice, coupled with the recent trend toward the use of digital spaces for doing so, have resulted in several researchers and educators using the term simulations to describe the work that they do to engage teachers in approximating practice. Not all researchers reference or use the term simulations to describe the tools they are developing and using to support K-12 science and mathematics teachers to engage in approximations of practice, even though in many cases it is a reasonable descriptor for the work. While the term is more commonly used in digitally mediated work than other forms of approximation, our use of it as an umbrella term is deliberate and intended to draw attention to the ways in which these face-to-face and technologically mediated approaches have more in common than might be assumed initially.

Using Simulations in Teacher Education

Over the last couple of decades, the field has seen an increase in the use of simulations as tools to incorporate approximations of practice into teacher education. Recent technological advances have supported the emergence of new kinds of digital simulations (e.g., simSchool, TeachLivE, and DtKids) and have brought increased attention to simulations as a tool to enhance teachers’ learning. Although defined variably across the literature, most note that simulations serve as models of reality that, while simplified, contain elements, behaviors, and processes found in the real world (Brown 1999; Dieker et al., 2014; Hume, 2012; Shapira-Lishchinsky, 2013).

Simulations – both face-to-face and technologically mediated versions – have clear potential for teacher learning. Simulations can provide an authentic, safe environment for teachers to explore different instructional strategies, engage in repeated practice, immediately see the consequences of their instructional choices, receive targeted feedback, and develop and practice emerging skills free of any risks to students in terms of negative learning consequences (Badiee & Kauffman, 2014; 2015; Brown et al., 2011; Garland et al., 2016; Girod & Girod, 2008; Grossman, 2010; Pankowski & Walker, 2016; Rayner & Fluck, 2014; Straub et al., 2014).

Simulations can be flexible and customized to train specific skills (Garland et al., 2016; Herbst & Kosko, 2014; Pankowski & Walker, 2016) or to offer a wider diversity of students (in terms of culture and learning needs) and situations than a novice teacher may be likely to encounter in field placement settings (Brown et al., 2011; Dotger, 2015; Mahon et al., 2010; McPherson et al., 2011; Straub et al., 2014). Simulations also can provide opportunities for repeated, focused practice on specific, highly relevant performance-based skills (Girod & Girod, 2008) and can be used intentionally to reduce the complexity of real-life situations, enabling participants to focus on developing specific skills (Dotger, 2015).

In reviewing the literature on the use of simulations in teacher education, we found that multiple projects have used face-to-face and technologically mediated simulations in a variety of ways, and a few robust programs have integrated them more widely into teacher preparation. Most programs focus on simulating secondary school students – either middle school, high school, or both (e.g., SimSchool; Chazen & Herbst, 2012) – with a fair degree of variation in instructional focus, including classroom management (Mahon et al., 2010; Pankowski & Walker, 2016), special populations (Eldevik et al., 2013; Garland et al., 2016); communicating with parents (Gerich & Schmitz, 2016), ethical decision-making (Shapira-Lishchinsky, 2013), professional identity (Carrington et al., 2011), or instructional skills in a particular content area, most often mathematics or science (Brown et al., 2011; Herbst & Kosko, 2014; Hume, 2012).

Notable examples of robust simulation implementations that are entirely face-to-face include the standardized student model used at the University of Michigan (Davis & Boerst, 2014) and the eduSIMS program used at Syracuse University (Dotger et al., 2014). Most research on these efforts has been largely limited to self-report of authenticity and learning, with few studies examining relationships between what is learned in simulation and classroom teaching (Ersozlu et al., 2020). Only a few studies to date (Cohen et al., 2020; Straub et al., 2014) examined the systematic variation of different simulation features in relation to effectiveness.

Since most of the work to date has focused on the active and immediate use of simulations, particularly in terms of supporting teachers in learning how to engage in generic teaching practices (e.g., classroom management), only recently has work focusing on content teaching emerged in the simulation space. As a result, considerably less attention has been given to the varied use cases that exist in mathematics and science teacher education or to the theoretical underpinnings of the simulations in these content areas, which are often implicit but less frequently articulated in simulation design. The goal of this study was to address this gap directly with a convened conference of stakeholders whose work has targeted developing, using, and studying simulations in mathematics and science teacher education.

Study Focus

In February 2019, we facilitated a Simulations in Teacher Education conference, which was funded by the National Science Foundation, in Louisville, Kentucky, with attendees from across the United States. The conference's primary goal was to provide opportunities for attendees to share their current research, theoretical models, conceptual views, and use cases focused on the design and use of face-to-face and technologically mediated simulations for building and assessing K-12 science and mathematics teachers' competencies. While most conference attendees developed and used simulations in the mathematics and science content areas, we also invited a few attendees whose work targeted instructional practices, dispositions, or skills that cut across content boundaries to provide avenues for further provocation.

Our study focused on identifying themes and patterns, based on conference attendees' perspectives and research, in response to three research questions: (a) How are simulations defined and used? (b) How do simulations work? (c) What evidence is being collected and what evidence should be collected about the use of simulations in preparing K-12 mathematics and science teachers?

The first question is an important one to consider, as the ways one discusses the key components and characteristics of simulations and their specific use cases has implications for the potential usefulness of conversations across bodies of work. In addition, understanding the ways simulations work is important to advance the field's collective thinking about the use of simulations in teacher education, especially in terms of specifying the mechanisms that support teacher learning and situating the work within a specific literature and theoretical space. Finally, to draw valid and reliable conclusions, the field needs to consider what tangible artifacts may provide evidence illustrating the effectiveness of simulations to support and assess teacher learning, which is a critical goal for the use of this innovative approach.

Methods

Study Context

The goal of this 2½ day conference was to begin a dialog that might culminate in greater consensus around theory and future research directions in this area. The conference consisted of multiple activities: an opening keynote discussing simulations as approximations of practice; three plenary sessions – each one with multiple presentations focused on a particular content area or focus (simulations in science, in mathematics, and for special student populations in these two content areas); poster presentations; small group debriefs; a spotlight on simulations session where attendees could experience some simulations firsthand; a panel discussion; and a set of roundtable discussions.

Prior to the conference, each attendee authored (or coauthored, if they were attending as part of a team) a short paper describing their work in simulations, the guiding theory of action that underlaid their ongoing work, the findings and results from their current work, and the questions that emerged from their work. Each attendee also reviewed a subset of the short papers and wrote a synthesis of the commonalities and variations noted in terms of how the various authors defined simulations, the theories of action described, and the lines of research and development employed across the projects represented. As appropriate, we drew upon these conference papers, presentations (see https://www.ets.org/research/events/simulations), and conversations, to advance the dialog beyond the group of conference attendees and into the larger field of teacher education.

Participants

To recruit conference attendees, we shared the recruitment flyer, which provided information about the conference purpose, goals, and timeline, via the listservs of various teacher education organizations, such as the Association for Supervision and Curriculum Development, Association of Mathematics Teacher Educators, Association for Science Teacher Education, National Association for Research in Science Teaching, and National Science Teaching Association. Our project team also reached out to those who had previously submitted a letter of interest with the grant proposal and other professional contacts to disseminate the flyer.

Prospective attendees completed a short, online survey describing their work and interest in simulations and their goals for attending the conference. The survey requested information about their current role in teacher education (e.g., K-12 teacher, researcher, teacher educator, graduate student, etc.), the population of teachers they worked with, a brief description of their work in the simulation space, and an explanation of what they hoped to contribute and learn from participating in this conference.

We purposefully selected conference attendees via an application process with a goal of representing work ongoing across mathematics and science teacher education, especially more emergent work and research that was less represented in the literature. In addition, our project team ensured that we selected attendees who used different kinds of simulations, who worked with varying teacher populations, and who represented variation in organizations and roles.

Thirty-eight conference attendees (26 females, 12 males) participated in the conference including 20 university faculty members or lecturers (most within teacher education), five researchers who worked in research centers within universities, four research scientists and one policy maker who worked at non-profit organizations, two simulation specialists who served as the human-in-the-loop in technologically mediated simulations (one at a university and another at a for-profit company), five graduate students or postdoctoral researchers, and one teacher candidate. Originally 39 conference attendees were scheduled to join the conference, but one conference attendee had an unexpected personal emergency and was unable to attend as planned. Since we did not have written permission from this person, we did not use this attendee's conference paper as part of this project's analysis.

Data Collection

The conference attendees' short papers, which included four to five pages they authored prior to the in-person conference, served as the primary data source to address the three key research questions about how simulations are defined and used, how they work, and the evidence that is and should be collected in this area. For each short paper, we requested that the conference participant or team include four sections: (a) project overview, (b) theory of action, (c) learnings, and (d) future directions.

In the project overview section, participants provided an overview of what their simulation project was, what activities it included, and what it sought to accomplish. They also defined the term "simulation" and explained what aspect of teaching practice their project simulated and the nature of the simulation they used, so that the reader would have a clear understanding of what their simulation work involved.

In the second section, conference attendees described the guiding theory of action underlying their simulation work by specifying the key features of the simulation model they used, how that model was hypothesized to develop teachers' competencies, and any theoretical frameworks they leveraged in their work. The objective of this section was to explain why the participants thought their simulation and associated specifications of the approach had the potential to support teacher learning.

In the learnings section, participants described their project's results, including the nature of the data and analyses they used to support the findings. Finally, in the last section, participants described what future research or development agenda they thought would be useful to the field and identified any open questions related to their current simulation work. In addition, we collected electronic copies of attendees' conference presentation slide decks and posters, as well as notes from the conference sessions, and used them as secondary data sources, as needed, to understand their perspectives and simulation research in response to the three research questions.

In total, 21 participant groups (either individuals or teams of participants) submitted a conference short paper; most of these groups also had a presentation slide deck or poster available for review. One additional participant group had a presentation slide deck and poster but did not author a conference short paper. For that group, the presentation slide deck and poster were used as the primary data sources. For this study, we report findings based on the 22 participant attendee groups who attended and shared their simulation work at the conference.

Data Analysis

We utilized a general qualitative inductive analysis approach (Creswell, 2009; Maxwell, 2013) to analyze data and identify patterns and themes related to each of the three research questions. In particular, we read across the conference papers and reviewed the conference presentations, posters, and notes to identify key features related to different aspects of each research question and developed a series of nine separate coding schemes to address the research questions. We analyzed each conference paper using these nine separate coding schemes and applied the relevant codes to specific excerpts within each conference paper using Dedoose, a qualitative data analysis program.

Each conference paper could receive multiple codes, as applicable, in each of the coding schemes. In addition, as needed, we used an "Other" code to indicate another aspect that was not captured by the main codes in that coding scheme, a "Vague" code when their written response was unclear and difficult to categorize, and a "Not Mentioned" code when they did not address a specific aspect in their paper or other materials.

Two researchers coded the conference papers from three of the participant groups to develop a shared understanding to applying each coding scheme and to refine the coding schemes, as needed. Then, the same two researchers double coded data from four of the 22 participant groups. Exact agreement (86.4%) and interrater reliability (0.820 intraclass correlation coefficient, or ICC) was within an acceptable range across the nine coding schemes. Any coding disagreements were resolved between the two researchers. After that, one researcher independently coded the remaining 15 conference papers and identified any coding difficulties for the other researcher to review and reconcile, as needed.

After coding the 22 participant groups' conference papers using these nine coding schemes and consulting the related resources, as needed, we calculated the number and percentage of responses representing each code and compared coding frequency to identify patterns and themes about how simulations are defined and used, how they worked, and what evidence was and should be collected about the use of simulations in preparing K-12 mathematics and science teachers.

Results

This section presents the results by the three research questions. For each research question, the codes that were applied are explained and a table illustrating the major patterns or themes resulting from the coding is presented. Then, examples from conference attendees' papers are described to highlight some of these patterns and themes.

Research Question 1

For the first question about how simulations are defined and used, we developed four separate coding schemes, as shown in Table 1. First, we identified four main characteristics, or features, that participants mentioned in their definitions of simulations, including how they served as approximations of practice, provided teachers with rehearsal spaces, could be standardized in their use across different teachers, or involved interactions between the teacher and the simulated students. Participants also noted the use of different simulation formats, including being human-driven, involving synchronous, real-time interaction, and engaging teachers in face-to-face or technologically mediated interactions. They also noted various simulation foci – either focused on individual teaching skills or broader teaching strategies. Finally, when describing the specific simulation use case, participants noted the use and importance of preparation or reflection activities as part of the larger cycle to support teacher learning. Table 1 shows the results about how the conference attendees defined and used simulations in their work.

Table 1 Simulation Characteristics and Use

Characteristics/Features	Participant Groups *n* (%)
Defining Simulations	
Approximation of practice	21 (95%)
Rehearsal space	21 (95%)
Standardized	12 (55%)
Interactive component	20 (91%)
Other	1 (5%)
Vague	0 (0%)
No definition provided	1 (5%)
Simulation Formats	
Human driven	20 (91%)
Synchronous interaction	22 (100%)
Face-to-face	8 (36%)
Technologically mediated	16 (73%)
Other	0 (0%)
Vague	0 (0%)
No simulation format mentioned	0 (0%)
Simulation Focus	
Individual teaching skill	12 (55%)
Teaching strategy	16 (73%)
Other	1 (5%)

Characteristics/Features	Participant Groups *n* (%)
Vague	0 (0%)
No simulation focus mentioned	1 (5%)
Simulation Use Case	
Preparation activities (prior to interaction)	14 (64%)
Reflection activities (after interaction)	21 (95%)
Other	0 (0%)
Vague	0 (0%)
No preparation or reflection activities mentioned	1 (5%)
Note. N = 22 groups	

Most attendees did not define the term simulation explicitly, although many described the nature of their own simulation or loosely identified it as a form of approximation (95% of participant groups), making it necessary to infer from their descriptions their underlying definition. As shown in Table 1, one common definition represented across most projects and conference attendees is the idea that simulations are responsive learning spaces (95% of participant groups), where preservice and in-service teachers can rehearse critical instructional practices essential to the work of teaching in these disciplines.

As Wild and Karamcheti (2019) noted, simulations are "learning experiences where teachers rehearse for important moves they make when interacting with students and adults" (p. 1). Inherent in these descriptions is the idea that simulations are not real because preservice teachers are working in spaces that approximate their work of teaching, albeit in situations where the students are not K-12 children but adults who are trained to behave and respond as K-12 students. Another commonality in defining simulations was the idea that the simulation was the part where this interactive piece occurred, which was noted by 91% of participant groups.

Across conference attendees, in most cases the uses of simulation we observed were human-driven (91% of participant groups), where the participant interacted in some format with another human, not with artificial intelligence or a preprogrammed game environment, and synchronous by occurring interactively in the moment (100% of participant groups). This synchronous interaction could occur via either a face-to-face format (36% of participant groups), where the participant could see the person who played the role of the student or parent, or in a technologically mediated one (73% of participant groups), in which the identity of the role-player was deliberately obscured or altered by the use of technology.

About half of conference attendees (*n* = 20) used an online environment consisting of digitally animated student and adult avatars to engage teachers in rehearsals of various instructional practices (as described in Bell, 2019; Berg, 2019; Berlin & Cohen, 2019; Chapman & Alvarez-McHatton; 2019; Garrett, 2019; Howell & Mikeska, 2019; Ingraham & Russell, 2019; Kretschmer & Kwon, 2019; Lange, 2019; Levin et al., 2019; Lew et al., 2019; Ware & Wernick, 2019; Wild & Karamcheti, 2019; Wilson et al., 2019). These student and adult avatars are controlled by a remote operator, known as the interactor or simulation specialist who controls the avatars' movements and is trained to interact and talk like students at particular grade levels with specific thinking profiles and personalities.

Other simulations are designed to involve face-to-face interactions between participants and others. These others are in some cases trained individuals, sometimes professional actors or teacher educators themselves, playing a specified or semispecified role (Arias & Davis, 2019; Boerst & Shaughnessy, 2019; Self, 2019; Walker, 2019). In other cases, they are peers role-playing the part of the student (Benedict-Chambers, 2019; Ghousseini, 2019), with varying levels of preparation to do so. While rarer, others use a mixed approach – employing both face-to-face and technologically mediated simulations in their work with teachers (Bondie et al., 2019) – or use digital or card-based games (Reich & Thompson, 2010) to approximate a part of the work of teaching that is generally noninteractive (e.g., designing rubrics for grading student work).

Another important feature across these varied simulations focused on the ways they approximate the full complexity of teaching. Some simulations are designed to address a skill as part of a larger teaching competency (55% of participant groups). For example, Reich and Thompson (2019) used game-based simulations to engage teachers in drills, whereby they practiced "non-teaching activities that help them develop skills and dispositions that are useful for teaching" (p. 1), such as eliciting student thinking. Other simulations are designed to provide teachers with opportunities to practice specific teaching strategies that involve a combination of teaching skills (73% of participant groups), such as learning how to facilitate science and mathematics discussions (Howell & Mikeska, 2019; Wilson et al., 2019) or how to engage in high-leverage practices for teaching English Learners (Ware & Wernick, 2019). Despite this variation in format and foci, the importance of opportunities for strategic and supported preparation (which was noted by 64% of participant groups) and reflection (which was identified by 95% of participant groups) to ensure teachers' productive engagement in and learning from simulations was a common element across many projects.

Research Question 2

To address the second research question about how simulations work, we developed a two-part coding scheme, as shown in Table 2. The first part of that coding scheme identified various aspects of participants' theory of action, including how they referenced the use of structured cycles of enactment, identified specific simulation features, or used reflection activities to support teacher learning. The second part of that coding scheme identified the various types of frameworks, theories, and literature that the conference participants referenced as grounding for their simulation work, such as Grossman's (2010) approximations of practice framework, specific learning theories, or studies or literature on gaming or the use of simulations in other fields.

We defined theories of action as specifying the key features of the simulation model in question and how the model is hypothesized to develop teachers' competencies. Theoretical grounding refers to the practice of situating the design, use, and study of these simulations in specific relevant literatures, such as learning theories, theories of professional learning for teachers, or the study of the use of simulations in other fields.

Table 2 Theories of Action and Theoretical Grounding for Simulation Design and Use

Aspect/Type	Participant Groups *n* (%)
Theory of Action	
References cycle of enactment	12 (55%)
Identifies specific simulation features	15 (68%)
Uses reflection activities	20 (91%)
No mechanisms to support teacher learning mentioned	0 (0%)
Theoretical Grounding	
Grossman's framework	7 (32%)
Learning theories	7 (32%)
Literature on gaming	1 (5%)
Literature on use of simulations in other fields	1 (5%)
No theoretical grounding mentioned	9 (41%)
Note. N = 22 groups	

As shown in Table 2, when describing their theory of action for the use of simulations, most participants mentioned specific simulation features

(68% of participant groups), such as the ability to customize the simulation to address specific teaching strategies, enact the simulation multiple times, or pause during the simulation. In addition, many of the theories of action noted using reflection activities (91% of participant groups). They also noted making explicit reference to cycles of enactment (55% of participant groups), in which some version of preparation, followed by simulation, followed by reflection made up the core components of that cycle.

These theories of action, however, tended to vary in grain size and detail, and were characterized by significant variation within the components of these cycles. Preparation ranged from minimally controlled to structured and reflection included activities such as written self-reflections, group activities, and structured coaching. The nature of the simulations also was variable relative to focus, number and nature of students and student ideas, and degree of standardization in protocols. It also varied with respect to basic parameters, such as whether pausing is available, how long the simulation lasts, and who is present in the room (and for what purpose) during the simulation.

One example was Garrett's (2019) elaboration of a clear and useful theory of action for their project's professional development approach, detailing the workshop, cycle of enactment of simulation, and the hypothesized effects on instruction and teacher self-efficacy. Each cycle of enactment was described as including practice, feedback, and reflection, components common to many of the models presented at the conference. Similarly, Wild and Karamcheti (2019) discussed a detailed framework they used for designing simulated tasks, which suggested specific characteristics as critical for determining what types of teaching competencies are likely to be supported effectively through simulations. Berlin and Cohen (2019) assigned preservice teachers randomly to different methods of receiving feedback to gauge the relative effectiveness of each method.

In general, findings also showed that conference participants were less likely to reference specific theories as grounding for their simulation work. When they did, they were equally likely to leverage Grossman, Compton et al.'s framework (32% of participant groups) or a specific learning theory (32% of participant groups). For example, Wilson et al. (2019) conceptualized teacher learning through the lens of Brown et al.'s (1989) situated learning theory. They used it to frame their claim that simulations, by being sufficiently like the work of teaching, should provide enough structure to support transfer of skills in the simulated environment to the real one. Lange (2019) situated his work in comparison to military simulation, which had a different body of literature available to draw upon.

Another example can be seen in Self's (2019) work, which is grounded in Gadamer's (1960/2011) notion of being "pulled up short," or placed into situations in which expectations are not met. These situations "cause PSTs [preservice teachers] to use these encounters as a critical incident that ground [sic] their concepts in both the general and particular moments being simulated" (p. 2). What is to be learned by the teacher-participants in this project is not a set of skills or approaches to teaching practice but the adoption of a particular stance of responsibilities toward students. The mechanism for that learning is participant sense-making of their own thinking and reactions and how they are grounded in their cognitive, behavioral, and affective orientations (Self, 2019).

Research Question 3

To address the third research question, we generated three coding schemes to address the following components: (a) outcomes, (b) approaches used for gathering evidence, and (c) types of claims generated, as shown in Table 3. Participants used simulations to support teacher learning on various outcomes, including teacher practice, knowledge, professional vision or identity, professional commitments to anti-oppressive education, agile thinking, and ability to work with special populations.

Likewise, codes for identifying the approaches they used to gather evidence during data collection included the use of scoring rubrics, qualitative analysis of teaching moves, self-report surveys, interviews, written or verbal reflections, observations of simulated teaching, and evidence of teaching in real classrooms. Finally, across conference participants, the coding scheme captured four main types of claims they generated in their work, including learning about how teachers work with students, identifying areas for teacher development, gathering support for simulations, and learning about the efficacy of using simulations. Table 3 provides an overview of the main patterns noted in these outcomes, approaches, and claims.

In their work, all conference attendees focused on developing mathematics and science teachers' competencies, such as helping teachers learn how to engage students in analyzing data or how to engage students in content-focused discussions. Yet, others moved beyond improvements to specific teaching competencies and considered potential impacts to teachers' knowledge (e.g., mathematical knowledge for teaching; 45%), professional vision or identity (14%), professional commitments to anti-oppressive education (18%), agile thinking (5%), and approaches to working with special populations (18%).

The attendees' focus on examining changes to teachers' practice used different approaches. In some cases, the focus was on analyzing teachers' performances within the simulation itself using highly structured and specified scoring rubrics or tools (32% of participant groups), such as Howell and Mikeska's (2019) use of a three-level scoring rubric (beginning novice, developing novice, and well-prepared novice) to assess five dimensions of facilitating high-quality discussions.

Table 3 Simulation Outcomes, Approaches, and Claims

Characteristics/Features	Participant Groups *n* (%)
Outcomes	
Teacher practice	22 (100%)
Teacher knowledge	10 (45%)
Teacher professional vision or identity	3 (14%)
Professional commitments to anti-oppressive education	4 (18%)
Agile thinking	1 (5%)
Ability to work with special populations	4 (18%)
Other	0 (0%)
No outcomes mentioned	0 (0%)
Approaches Used for Gathering Evidence During Data Collection	
Scoring rubrics	7 (32%)
Qualitative analysis of teaching moves	11 (50%)
Self-report surveys	4 (18%)
Interviews	4 (18%)
Written or verbal reflections	18 (82%)
Observations of simulated teaching	12 (55%)
Evidence of teaching in real classrooms	5 (23%)
Other	6 (27%)
No approaches mentioned	0 (0%)
Types of Claims Generated	
Learn about how teachers work with students	19 (86%)
Identify areas for teacher development	16 (73%)
Gather support for simulations	7 (32%)

Characteristics/Features	Participant Groups *n* (%)
Learn about efficacy of using simulations	15 (68%)
Other	0 (0%)
No types of claims mentioned	2 (9%)
Note. N = 22 groups	

Similarly, Arias and Davis (2019) also developed and used scoring rubrics (levels included does not meet, partially meets, or meets expectations) of the preservice elementary teachers' performances in the simulated student interviews across three areas (a) using representations to analyze data; (b) constructing evidence-based claims; and (c) science knowledge of teaching. A third example is Berg's (2019) use of technology to capture real-time data during simulation sessions about the science teaching moves employed.

Another approach used to discern whether teachers incorporated specific practices into their instruction was by in-depth qualitative analysis of specific teaching moves used during the simulation (50% of participant groups). For example, Levin et al. (2019) examined how preservice secondary science teachers engaged student avatars in constructing explanations for scientific phenomena by coding transcripts from the video-recorded interactions for two features – the type and nature of teachers' responsiveness towards students' contributions and the extent to which teachers provided opportunities for students to engage in intellectual work.

Although only represented within a few projects (23%), another approach was to collect evidence teachers could engage in specific teaching practices back in classrooms with real students. For example, Garrett's (2018) study used a randomized control field trial of the Simulated Instruction in Mathematics Professional Development program to determine the extent to which active learning and repetition with an online digital classroom environment helped teachers learn how to pose purposeful questions and facilitate meaningful mathematical discourse with elementary and middle school students in mathematics classrooms.

In addition to these approaches to examining the extent to which teachers' actual instructional practices shifted as they engaged in various simulations, other commonly mentioned mechanisms to examine potential impact were using self-reported surveys (18%), interviews (18%), or reflections (82%). Others used a compilation of instruments to determine if teachers' practice had shifted as a result of their use of simulations. For example, Lew et al. (2019) used interviews, observations of multiple simulated performances, and surveys to determine the extent and ways in which preservice teachers incorporated linguistically responsive teaching strategies when teaching mathematics and science.

One of the main take-aways from the current evidence is that one can learn about teachers' use of specific instructional practices or teaching moves via the use of face-to-face and technologically mediated simulations (86% of participant groups). That is, one can discern information about the ways in which preservice and in-service teachers approach and work with students around specific mathematics and science content when they use these different types of simulations. Most importantly, the use of these simulations provides a lens through which teacher educators and teachers, themselves, can identify areas for continued development (73% of participant groups).

These claims are probably the ones best supported by the evidence, as many projects have used various methods and instruments to gather data about teachers' instructional practices when using simulations. In addition, the evidence collected to date suggests that teachers' perceptions of working with simulations tend to be positive and supportive in nature (32% of participant groups). They tend to value working with simulations as practice-based spaces that allow them to build their teaching competencies and identify areas where they need to continue to grow. The field would likely want to make many other claims, as well, but further evidence is needed to do so. The most likely claims are ones regarding the efficacy of using simulations in teacher education, which was addressed in 68% of the participant group's work.

One such question is *whether* simulations work at all in mathematics and science teacher education, and if so, how well, under what conditions, for which outcomes, and at what point in a prospective or in-service teacher's professional trajectory? Some studies have addressed the question of efficacy of simulations, although most rely on self-report from preservice teachers rather than structured experimental design. A notable exception to this assertion is in the work of Garrett (2019), whose study used a randomized control design to evaluate the effectiveness of the simulation-based professional development program. In addition, Cohen and Berlin's (2019) study used an experimental design to examine the effects of coaching and self-reflection on supporting teachers' learning from simulations, while Howell and Mikeska's (2019) research included a comparison of preservice teachers' ability to facilitate argumentation-focused discussions across treatment and control groups.

Some researchers have been more directly focused on the use of simulations for assessment than directly to support teacher learning and during their work have investigated the validity and reliability of the simulations as measurement tools (e.g,. Berlin & Cohen, 2019; Boerst & Shaughnessy, 2019; Ware & Wernick, 2019). A second type of efficacy question could focus on the transferability of skills learned in simulation to classroom practice. Several conference participants called out the importance of future work examining what is, arguably, the most critical long-term outcome of the work, but only a few projects directly addressed this question in their design.

Discussion

In general, we found that while conference attendees' ideas about the key characteristics and criteria used to define simulations had much in common, they were not identical, which suggests the field has not yet produced a coherent vocabulary to describe simulations productively. Teacher education would benefit from a proposed working definition to ground the ongoing work in the practice-based teacher education space. That definition should be precise and sufficiently broad to promote dialogue. Following is a list of commonalities noted by conference attendees, which mapped onto key characteristics noted in the broader simulation literature. We will then build off these commonalities to propose a working definition of simulations for use in teacher education contexts.

First, clear agreement emerged across projects that practice teaching with real students, even if mediated or supported in some ways, is not a simulation of teaching, but it is teaching itself. Second, despite the specific foci or format, the use of a human-in-the-loop – be it a simulated adult (acting as a parent) or a simulated student (or group students) who is designed to respond as an elementary or secondary student – was a common element across most simulations. These simulated adults or students could appear face to face during the simulations or through a technologically mediated environment with avatars. Such formats for simulations were also represented in the broader literature in practice-based teacher education (Davis & Boerst, 2014; Dotger et al., 2014; Straub et al., 2014, 2015).

Many conference attendees also agreed with the notion that simulations offer learning opportunities aligned and relevant to but do not recreate the full authenticity of the work of teaching. The opportunity to focus in on a nuanced skill or aspect of the work of teaching – and purposefully not addressing the full complexity of teaching – is part of the reason for their potential usefulness as tools to support teachers in learning.

As noted earlier, most of the current literature discusses simulations as models of reality (Brown 1999; Dieker et al., 2014; Hume, 2012; Shapira-Lishchinsky, 2013), but as models they fail to represent accurately all aspects found in the real world. Simulations can thus target specific aspects of the work of teaching, thereby reducing the typical complexity teachers encounter when working with real students.

Finally, the working definition most projects adopted of simulation tends to account for simulating the interactive work of teaching, although some projects did tackle some of the noninteractive components of teaching, such as developing rubrics and interpreting student ideas shown in written work. Simulations are seen as productive tools for teacher learning because they provide opportunities for teachers to engage in repeated, focused practice on instructional skills that are essential to the work that they do in classrooms (Girod & Girod, 2008) and can be used to reduce complexity so teachers can hone in on developing specific teaching skills (Dotger, 2015).

Based on the themes noted within the broader literature on simulations and the conference papers, we propose the following working definition of simulations for use in teacher education contexts:

Simulations are responsive learning spaces where preservice and in-service teachers can rehearse critical instructional practices or specific skills essential to the work of teaching in situations of reduced complexity. These learning spaces can target the interactive, in-the-moment, responsive work of teaching, such as eliciting student ideas or facilitating student-led discussions, or the noninteractive components, such as planning, grading, providing written feedback on work, or interpreting student data. Simulations do not involve interactions with real students; instead, they typically involve synchronous and human-driven interactions, where the participant interacts via a face-to-face format or through a technologically mediated environment with one or more adults who act as K-12 students.

Such a definition helps one to see that student teaching and teaching in settings of reduced complexity, such as working with individual students or small groups of students, while still useful approximations of practice, would not be considered simulations of teaching. However, focused drills where teachers have an opportunity to interact with one or more peers as they act as fifth graders with specific alternative conceptions and try to elicit those student ideas from their peers would be a form of simulated teaching.

Most of the simulations in mathematics and science teacher education in this study (91% of participant groups) involved a human-in-the-loop. This finding suggests that notions about simulations as primarily computer driven is not the norm in mathematics and science teacher education, although future technological advances may pave the way for the use of artificial intelligence solutions to power these interactions. For now, these simulations remain a deeply human activity.

One of the most common theories cited was Grossman, Compton et al.'s (2009) framework of pedagogies of enactment, particularly that of *approximations of practice*, or related work around practice-based teacher education (Ball & Forzani, 2009) and rehearsals (Lampert et al., 2013). Common to all these theories is the idea that teachers learn to teach by, quite literally, practicing teaching or its component parts. This idea is clearly an appropriate grounding for work in simulations, particularly as simulations provide a unique way to practice component parts of teaching in more controlled and low-stakes settings than real classrooms.

Grossman's framework is much more a useful framework for situating theories of action than it is a grounding theory of teacher learning, as the objects described are pedagogical approaches rather than ways of learning, holding, or applying knowledge or skill. In other words, Grossman, Compton et al.'s (2009) attention was on the types of learning opportunities that might be employed to support teacher's improved teaching practice.

An overreliance on this theory alone could be problematic in many ways. For example, the notion is unclear that practice-based teacher education accounts for the learning of stances or orientations like those raised by Self (2019) as well as it does the applications of skills or habits of mind. The notion of *approximation* (Grossman, Compton et al., 2009) implies, theoretically, that value is found in the approximation being different than the object that is approximated. In other words, the approximation is not simply a more convenient, if potentially less authentic, substitute for the real thing (Howell et al., 2019).

Grossman, Compton et al.'s (2009) work is appropriate for exploring the affordances of approximation but may be less well-suited to support research questions in which simulation is simply a context to learn about other constructs. Examples include research that seeks to correlate teacher performance with other variables using simulation more as a standardized measure than a learning tool, especially within the complexity often found in content-focused instruction.

Our primary takeaway on this topic is that a tremendous amount remains to be studied and understood about simulation, including careful approaches to the development of theory alongside practical considerations of design and use. Most importantly, attending more closely to a general theory of action and less to theoretical grounding is consistent with our reading of the literature on simulations more broadly and is a place the field could push for more clarity. Well-articulated theories of action that are directly connected to research goals and theoretical stances would help to inform decisions about what data should be collected in service of specific goals and aims.

Findings also suggest that conference attendees' work in this space often aimed both to produce teacher learning and to amass evidence of teacher learning using simulations. In general, the evidence presented is largely descriptive in nature, although some projects also collected quantitative data, and several used control group methodologies to begin to establish causal mechanisms. Similar observations surfaced in our review of the broader literature on simulations for teacher learning. The majority of studies leveraged self-report from teachers about their experience engaging in the simulations to discern learning outcomes. Only a limited number of studies extended their research to examine impact in real classrooms (Ersozlu et al., 2020) or to examine directly how different simulation features impacted the simulation's effectiveness for teacher learning (Cohen et al., 2020; Straub et al., 2014).

In terms of rigorous research, a clear priority for the field should be establishing links between simulation approaches, teacher learning, transfer of that learning to classroom environments, and ultimately, student learning. This list is not a simple chain of inferences to support and falls into a larger gap in the field around finding evidence of transfer between learning and application context (Ersozlu et al., 2020). The same critique could be leveraged about studying the efficacy of student teaching, for example. The field seems to feel a strong need to justify the use of simulations, because they are novel, sometimes expensive to implement, and less obviously authentic to real teaching.

That said, connecting teacher learning to student learning is notoriously difficult. Precise theories of action can help in this process by disentangling the multiple links in the inferential chain, allowing individual researchers to focus clearly on one inference at a time in ways that others can build on.

Implications for Teacher Education

Findings from this study point to three main implications. First, those who are designing and studying simulations within K-12 mathematics and science teacher education settings must begin to specify more directly the theory of action and theoretical underpinnings for the simulation models and approaches they are using. Such specifications should include explanation of the specific simulation features that are hypothesized as critical mechanisms for teacher learning and describe use cases that support productive learning.

Second, in this article, we proposed a working definition of simulations for use in teacher education settings as a starting point to build from. Better understanding and agreeing on what counts as a simulation and what approaches may be similar to but outside of specified boundaries will be useful to ensure that the objects of study are clearly delineated. Most important is explanation around the intervention being studied. Findings suggest that most simulation approaches used by conference attendees embedded the simulated teaching experience within a larger cycle of enactment, including preparation and debrief/reflection activities. Specifying whether the intervention includes the full cycle or only the simulated teaching aspect is critical for both understanding hypothesized theories of action and for comparing results across simulation research studies to generalize across contexts and use cases.

Finally, collective research across simulations would benefit from examining claims that specific features or components of simulations and the activities used in combination with the simulations are differentially effective to support learning. Comparative studies using systematic and structured variations around specific design parameters, including parts of the learning cycle (e.g., variation in the pre- and postsimulation activities), would be useful to supporting claims about how simulations work best, for whom, and under what conditions.

Study Limitations

The main limitation of this study regards who participated in this conference. While we purposefully recruited from a wide variety of professional organizations and contacts and then strategically selected from the larger pool to ensure as diverse representation as possible, we recognize not every researcher, teacher educator, or graduate student working in this area was able to apply or attend this conference. However, this limitation was mitigated somewhat by the fact that many of the findings in conference outcomes mapped onto the broader simulation literature that had already been established in the field.

Another limitation relates to the data sources used for this analysis. The conference short papers served as the primary data sources of the main patterns in conference attendees' perspectives. While we directly explicated the key components of the conference papers, some conference attendees possibly interpreted the short paper instructions differently than intended. In addition, for feasibility purposes, we encouraged these conference papers to be concise (about four to five pages, at most) and, as such, specific aspects may not have been addressed or explained in as much detail as would be possible with more space.

Conclusion

Approximating practice is one of the key pedagogies of practice-based teacher education that is increasingly used to support and assess teachers' competencies in various content areas. Simulations – face-to-face and technologically mediated ones – have the potential to serve as productive tools to engage teachers in simulating components of the work of teaching. Simulations, as practice-based spaces that include the accompanying preparation and reflection learning opportunities that surround them, engage teachers in activities that produce various tangible outcomes for analysis and inference. Based on the collective work represented across conference attendees, promise in this area is great, but much progress is needed for this work to reach its full potential and impact.

The emphasis on self-report using surveys, interviews, and reflections to gain insights into teachers' perceptions about the usefulness of these simulations and the ways in which they impact their practice, as well as research examining potential shifts in teachers' instructional practice, knowledge, and professional vision, serve as foundational steps to begin to understand how, in what ways, and under what conditions simulations can be used to support and assess mathematics and science teachers' learning. However, more robust evidence linking the use of simulations to both teacher outcomes and student outcomes is needed to make more generalizable and stronger claims about the efficacy of simulations.

The field of mathematics and science teacher education also needs to employ experimental and quasi-experimental designs, where possible, in which various features of these simulations and learning cycles are deliberately varied to create authentic and responsive learning spaces for teachers. Examining what deliberate controls on complexity in different simulations are most likely to generate productive opportunities for prospective teachers to learn is one avenue that is likely to support the field in developing more robust hypothetical learning trajectories involving the use of simulations. The work required to figure out collectively how to do so is worth the effort.

Note

[a] This usage is not entirely congruous with the use of the term in other fields. In theater, for example, rehearsal may be centered around scripted interactions rather than improvisation (Mitter, 2006), and cognitive science defines rehearsals as repetitive processes affecting memory in terms that are unlike the description used in the literature on teaching (Craik & Watkins, 1973). The literature on teaching that uses this term generally refers to a form of rehearsal that is improvisational, adaptive, and less scripted than parameterized. Throughout the paper we use the term as intended by the contributing projects, but we note this distinction from common use for the reader to avoid possible confusion.

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